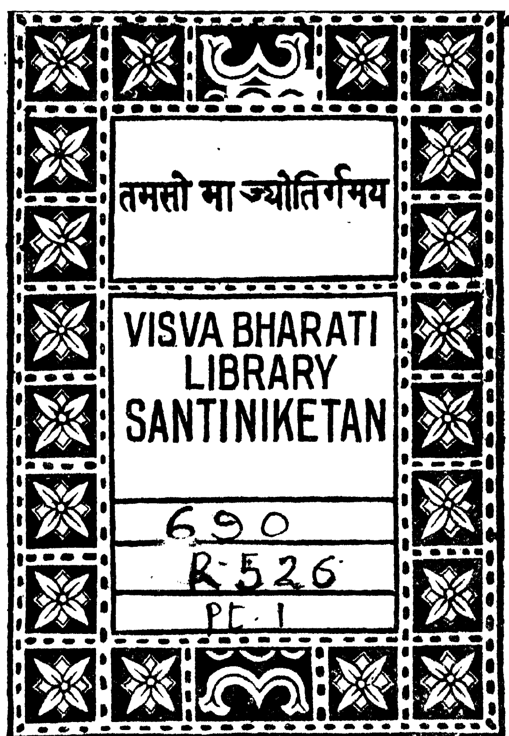


RIVINGTON'S NOTES

ON

BUILDING CONSTRUCTION

PART I

RIVINGTON'S

NOTES ON BUILDING CONSTRUCTION

NEW EDITION, ENTIRELY REWRITTEN.

LIST OF CONTRIBUTORS (Part I)

PATRICK ABERCROMBIE, M.A., Lecturer on Building Construction, Liverpool University.

REGINALD BLOMFIELD, M.A., R.A., F.S.A., F.R.I.B.A., Past-President R.I.B.A.; Hon. Fellow of Exeter College, Oxford. (*Introduction only.*)

W. DOUGLAS CARÖE, M.A., F.S.A., F.R.I.B.A.

A. W. S. CROSS, M.A., F.R.I.B.A., Vice-President R.I.B.A.

E. FIANDER ETCHELLS, Hon. A.R.I.B.A., A.M.Inst.C.E., A.M.I.Mech.E., Member of Boards of Examiners, Inst.Mun.E. and Soc.E.(Inc.); Building Act Section, L.C.C.

BROOK KITCHIN, F.R.I.B.A., Architect to the Local Government Board.

H. V. LANCHESTER, F.R.I.B.A., Vice-President R.I.B.A.

ALAN E. MUNBY, M.A., F.R.I.B.A., Hon. Examiner and Past-Chairman of Science Standing Committee, and Past-Member of Council R.I.B.A.

Professor BERESFORD PITE, F.R.I.B.A., Professor of Architecture, Royal College of Art, South Kensington.

WILLIAM PYWELL, F.R.I.B.A., Medallist, Architectural Association, London.

Professor C. H. REILLY, M.A., F.R.I.B.A., Professor of Architecture, Liverpool University; Past-Member of Council R.I.B.A.; Member of Board of Architectural Education R.I.B.A.

W. T. SWEETT, Secretary of the British Institute of Certified Carpenters, Examiner in Carpentry to the City and Guilds of London Institute.

W. NOBLE TWELVETREES, M.I.Mech.E., A.M.I.E.E., M.Soc.Ing.Civ., Past-President Civil and Mechanical Engineers' Society, Member of Board of Examiners, Soc.E.(Inc.).

HERBERT W. WILLS, F.R.I.B.A., Editor of *The Builder*.

RIVINGTON'S NOTES

ON

BUILDING CONSTRUCTION

A BOOK OF REFERENCE FOR ARCHITECTS
AND BUILDERS
AND A TEXT-BOOK FOR STUDENTS

PART I

EDITED BY

W. NOBLE TWELVETREES

NEW IMPRESSION

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PREFACE

The first edition of this work, published forty years ago, was intended primarily to assist students preparing for the examinations in Building Construction held under the direction of the Board of Education, South Kensington. It was hoped also that they might be found useful by others engaged in designing or erecting buildings. There is ample reason for the statement that the practical value of *Rivington's Notes* has been fully appreciated by successive generations of students, as well as by architects, builders, and others concerned in building construction. Although the subjects discussed and the general arrangement of the text were based upon the Syllabus of the Board of Education, the work soon acquired a justly deserved reputation as a standard text-book for all classes of students requiring information on the design, construction, and equipment of buildings, and particularly as a book of reference for architects and builders.

With the object of maintaining this two-fold reputation, Part I has been revised on six occasions, the last edition including some important additions and a useful rearrangement of the chapters. After the lapse of a further period of nearly ten years it became evident that something more than a mere revision would be necessary to bring the work thoroughly into line with modern practice. Consequently, on the recommendation of the present Editor, Parts I and II have been entirely rewritten by well-known architects and others having special knowledge on certain subjects. Most of the illustrations are entirely new, the remainder having been selected from those which appeared in previous editions.

Having regard to the widespread use of *Rivington's Notes* the Editor has disregarded the original idea of basing the arrangement of the subject-matter upon one out of the many courses of study recommended in the present day, and has attempted to follow a purely logical sequence in arranging the order of the subjects discussed.

Thus, Part I deals first with matters requiring attention before the commencement of building operations, and then with forms of construction by the aid of which buildings of different types can be carried up from foundation to roof level. Part II deals first with roofs and classes of work which appertain to the finishing of buildings for occupation, and subsequently with various branches of domestic engineering.

While all the chapters in Part I will be found to contain a large amount of new matter, apart from the treatment of original matter in a new form, attention may be drawn to the introduction of chapters on the important subjects of Building Regulations; Damp- and Sound-Resisting Construction—Prevention of Dry Rot; Steel Skeleton Buildings; Reinforced Concrete, Reinforced Brickwork, and Concrete Blocks; and Fire-Resisting Construction.

The Appendix contains selected Examination Questions from Papers set by the Royal Institute of British Architects, the Board of Education, the City and Guilds of London Institute, the Surveyors' Institution, the Royal Sanitary Institute, the Municipal School of Technology, Manchester, and the Royal Technical College, Glasgow.

Finally, it may be remarked that the List of Contributors printed opposite the title-page of each Part should be sufficient to indicate the authoritative character of the work, but the reader should note that the chapters by contributors holding Government and other public appointments are of strictly unofficial character.

W. NOBLE TWELVETREES.

195 BEDFORD HILL, S.W.,
June 1915.

CONTENTS OF PART I

INTRODUCTION

BY REGINALD BLOMFIELD, R.A., F.S.A., F.R.I.B.A.
Past-President of the Royal Institute of British Architects.

Rivington's Notes on Building Construction were first published in 1875. The original publication was an admirable work, a little uncertain in the choice of its illustrations, but clear, straightforward, and easily intelligible. There must be many architects still living who look back to that work with gratitude and esteem as their first introduction to the rudiments of building. In the last thirty years, however, building construction has developed in many directions. Reinforced concrete and steel-framed buildings have introduced new factors which must be reckoned with seriously by the architect, and indeed have become indispensable for certain classes of buildings. There are besides many inventions in detail and material, which, properly handled, may contribute to efficiency and economy in building, and with which it is therefore necessary for the architect to acquaint himself. Indeed the number of these discoveries has added greatly to the complexity of the modern practice of architecture. When only one or two methods of construction and limited materials were available, the architect could devote his energy to the perfecting of his expression in his art. Nowadays he has to select one method out of many, and, owing to the ingenuity of modern construction, problems are presented to him which could never have been attempted fifty years ago. It is therefore vital that he should, at any rate, know his way about among these methods, and this is the object of the present edition of Parts I and II of *Rivington's Notes*. Both Parts have been written by practical architects for architects, supplemented by some most useful contributions from engineers on matters of construction which are common to both architects and engineers. There can be no doubt that keen students, with real qualifications for architecture, but an ingrained ineptitude for mathematics, have sometimes been checked at the outset of their studies by collections of formulae which they could not apply. The knowledge of certain rules and formulae of construction is, of course, essential, but in the following pages these have so far as possible been reduced to a minimum, and the writers have devoted themselves to furnishing such information as is necessary for the actual purposes of building. Their object has been to lay a sound foundation of practical knowledge, and I think they will be found to have done so in a very complete and concise manner.

Such a foundation, though indispensable, is of course only a part of the architect's training. Good architecture must be based on sound construction, but it by no means follows from this that sound construction

is always good architecture. A building may be very well built, may even answer its practical purpose, and yet be awkward, ugly in form, vulgar in proportion, unpleasant in colour, and bad in taste, and architectural students should never lose sight of the vital quality which differentiates architecture from mere construction. When an architect has to design a building he must, as a matter of course, see to it that it answers the purpose for which it was designed, and that it is soundly built; but this is only the ground-work of his real task. He has to set his imagination to work on the grouping and blocking of his building, on the possibilities of effect latent in the plan, he has to search out harmonious proportions between the parts of his building, he has to use fine selection in his materials, and in the treatment of the work in detail. All this means wide knowledge and constant consideration of these problems, and essentially that foundation of imagination and artistic capacity, without which, though a man may run a very successful business, he will never be an architect. The student should bear this constantly in mind in his study of construction. He must master it for all practical purposes, because it is impossible to design buildings without knowing how to build and the limits of construction. But whereas to the engineer a mastery of the problems of construction is the final end of his studies, with the architect this mastery is a means to an end, a part only (though a vital part) of the technique of his art. An architect is an artist in plastic form, and, as such, should neglect no opportunity of adding to his mastery of form, and of developing his power of designing the forms most perfect for their purpose, only the term "purpose" must be given a widely extended sense. It is not to be limited to merely utilitarian purpose. When we are dealing with architecture we must include in "purpose" the appeal to the imagination and the aesthetic sense.

With this proviso, the more thoroughly the architectural student is grounded in knowledge of building materials and construction the better. The more complete his knowledge of them, the wider will be the range of his expression; and the knowledge that he acquires from this text-book of construction he should visualise and fix in his mind by constant reference to buildings in course of construction. Architecture is an exact art, limited by definite conditions, and does not admit of the "à peu près," and I need scarcely remind the artist that it is in those very conditions that he will find the jumping-off point for his imagination and his faculty of design.

REGINALD BLOMFIELD.

NEW COURT, TEMPLE,
June 1915.

CHAPTER I

BUILDING REGULATIONS

BY BROOK KITCHIN, F R.I.B.A.

EVERY architect should possess some knowledge of the laws relating to building and should acquaint himself with the local Acts, byelaws and requirements of the district in which he may be engaged in building operations if he wishes to minimise the chances of conflict with the local authorities.

A knowledge of the requirements of the particular area in which he may be principally engaged will not necessarily serve him in other localities, and it will be advisable to make enquiries from the Clerk or Surveyor to the local council as to what Acts, byelaws, or regulations are in force in the particular district where he may be about to undertake professional work.

It is not unusual for architects to leave the submission of plans for approval entirely in the hands of the builder. This is not always advisable, and a preliminary interview by the architect with the Surveyor or Clerk to the local council will frequently obviate or remove misunderstandings which might otherwise arise.

In the following pages the ordinary legal enactments affecting building operations are briefly summarised. It has not been possible, within the limits of a single chapter, to refer to any cases of litigation which have arisen out of the Acts and byelaws. Reference to these can be obtained by consulting the numerous handbooks, relating to the various Acts, that have been published from time to time and which can be obtained through any bookseller or direct from Parliamentary publishers.

ENGLAND AND WALES

LONDON

Acts, Byelaws, and Regulations.—Architects practising in London will be concerned mainly with the provisions of the London Building Act of 1894, and also with the following Acts and byelaws, and with the regulations made by the London County Council under the numerous General Powers Acts for special purposes.

District Surveyors.—The District Surveyors, under the authority of the London County Council, are the administrative agents for all building matters under the London Building Acts.

Sanitary Authorities.—All byelaws and regulations as to drainage and sanitary matters generally are administered by the Borough Councils and the Corporation of the City of London, who are the authorities for this purpose under the Metropolis Management Acts as amended by the Local Government Act of 1899 and under the general powers of the City Corporation, and the Public Health (London) Act, 1891.

Submission of Plans. — Plans and other particulars of buildings and drainage have to be submitted to the District Surveyor and to the Borough Council or to the Corporation respectively.

London Building Act, 1894.—The following indicates the general scope of the requirements under the London Building Act, 1894, governing the erection of buildings in the County of London:

Ordinary Buildings.

- Building lines, which are subject to the determination of the Superintending Architect (Part III. sec. 22 *et seq.*).
- Light, ventilation, open space about buildings, courts (Part V. sec. 39 *et seq.*).
- Height of buildings (Part V. secs. 47, 48, 49).
- Structure of foundations, walls, roofs, floors, chimneys, and flues (Part VI. sec. 53 *et seq.*, and First Schedule).
- Staircases (access and ventilation, Part VI. secs. 68 and 69).
- Height of rooms (Part VI. sec. 70).
- Balconies, cornices, projections, etc. (Part VI. sec. 73).
- Separation and uniting of buildings (Part VI. secs. 74 to 77).

Public Buildings.

- Construction to be approved by the District Surveyor (Part VI. sec. 78).
- Conversion of houses, etc., into public buildings (Part VI. sec. 79).
- Staircases (Part VI. sec. 80).

Special and Temporary Buildings.

- Application to and control of L.C.C. (Part VII.).
- Licences for wooden structures (Part VII. sec. 84).

Rights of Owners (Part VIII.).

Dangerous and Neglected Structures (Part IX.).

Dwelling Houses on Low-Lying Land (Part XI.).

Materials and Thickness of Walls (Schedule I.).

Fire-resisting Materials (Schedule II.).

Fees payable to District Surveyors (Schedule III.)

Byelaws (under Part XIV. sec. 164) with respect to:

- The regulation of the plans, level, width, surface, and inclination of new streets, and for regulating the plans and level of sites for new buildings.
- Foundations and sites of buildings, and other erections.
- The mode in which, and the materials with which, such foundations and sites are to be made, excavated, filled up, prepared, and completed for securing stability, and for the purposes of health.

The thickness and the description and quality of the substances of which walls may be constructed for securing stability, the prevention of fires, and for purposes of health.

The dimensions of wooden bressummers.

The dimensions of joists of floors.

The protection of ironwork used in the construction of buildings from the action of fire.

Woodwork in external walls.

The description and quality of the substances of which plastering may be made.

The mode in which, and the materials with which, any excavation made within a line drawn outside the external walls of a house, building, or other erection, and at a uniform distance therefrom of 3 feet, shall be filled up.

The regulation of lamps, signs, or other structures overhanging the public way, not being within the City (administered by the local authority).

The means of escape from fire in buildings exceeding 60 feet in height.

London Building Act (Amendment) Act, 1898.

Notices to set back buildings.

Height of certain working-class dwellings.

Dangerous or neglected structures.

London Building Act (Amendment) Act, 1905.

Protection of buildings against fire.

Means of access to roofs.

Conversion of buildings.

Definition of fire-resisting materials.

Metropolis Management Acts, 1855, 1862, 1890, 1899.

As to drains and sewers, including byelaws for regulating the material of the pavement and roadway of new streets, and for regulating the dimensions, form, and mode of construction of the pipes, drains, and other means of communicating with sewers and the traps and apparatus connected therewith.

Metropolis Management Act, 1878.

Regulations made under this Act with respect to new theatres and music-halls for protection from fire.

Public Health (London) Act, 1891.

Byelaws as to water-closets, earth-closets, privies, ashpits, cesspools, and receptacles for dung, and the proper accessories thereof in connexion with buildings.

London County Council (General Powers) Act, 1908 (Part III.).

Cubical extent of buildings.

Rules as to uniting buildings.

Division walls, plans, etc.

London County Council (General Powers) Act, 1909.

Regulation of iron and steel frame construction.

Power of Council to make byelaws as to buildings of reinforced concrete.

Factory and Workshops Act, 1901.
As to means of escape and the construction of staircases, and generally as to gangways, doors, lifts, windows, etc., in factories and workshops.

Tribunal of Appeal.—The Tribunal of Appeal (L.B.A. 1894, sec. 175 *et seq.*) consists of three members appointed for a period of five years, by (1) a Secretary of State, (2) the Council of the Royal Institute of British Architects, (3) the Council of the Surveyors' Institution.

The Tribunal exercises judicial functions in deciding the appeals against the decisions of the London County Council, the Superintending Architect, and the District Surveyors.

Appeals may only be made in respect of certain matters referred to in the Act, the most important of which, so far as architects practising in London are concerned, being (sec. 19) against the refusal or conditional sanction to the formation or laying out of a street; (sec. 41) as to open space in rear of a domestic building; (sec. 43 (ii)) as to deviation from plans; (sec. 48) against the refusal of the Council to consent to the erection of a building of a height greater than is prescribed by the Act; (sec. 5 (8)) as to the definition of the "level of the ground"; (sec. 22) as to building lines; (sec. 78) against the disapproval of the District Surveyor of a public building; and (sec. 79) conversion of buildings into public buildings.

Appeals must be made within fourteen days after the decision has been made, except in the case of sec. 48, relating to the consent of the Council to allow a greater height of buildings, in which case twenty-one days are allowed.

PROVINCES

In the provinces the erection of buildings is controlled by the Town Councils in the boroughs and larger towns, and by the Urban District Councils in the smaller towns. In the rural districts the Rural District Councils are the controlling authorities.

Byelaws in Boroughs and Urban Districts.—For the most part building regulations in all these areas are in the form of byelaws under the Public Health Acts, 1875 and 1890, based on the Local Government Board's model code, though in several of the principal towns there are special local acts in force dealing with building matters.

The following extract from the memorandum issued by the Local Government Board in 1877 summarises generally the powers of the local authorities (Urban District Councils) in this respect, and indicates the procedure to be adopted in connexion with the deposit of plans and their approval.

"Section 157 of the Public Health Act, 1875 (38 & 39 Vict. c. 55), provides that every Urban Authority may make byelaws with respect to the following matters; that is to say,

"(1) With respect to the level, width, and construction of new streets, and the provisions for the sewerage thereof;

"(2) With respect to the structure of walls, foundations, roofs,

and chimneys of new buildings, for securing stability and the prevention of fires, and for purposes of health;

"(3) With respect to the sufficiency of the space about buildings to secure a free circulation of air, and with respect to the ventilation of buildings.

"(4) With respect to the drainage of buildings, to water-closets, earth-closets, privies, ashpits, and cesspools in connexion with buildings, and to the closing of buildings or parts of buildings unfit for human habitation, and to prohibition of their use for such habitation;

"And they may further provide for the observance of such byelaws by enacting therein such provisions as they think necessary as to the giving of notices, as to the deposit of plans and sections by persons intending to lay out streets or to construct buildings, as to inspection by the Urban Authority, and as to the power of such Authority (subject to the provisions of this Act) to remove, alter, or pull down any work begun or done in contravention of such byelaws."

In connexion with the subject of byelaws with respect to new streets and buildings the two following sections (158, 159) of the Act are important.

"(Section 158.) Where a notice, plan, or description of any work is required by any byelaw made by an Urban Authority to be laid before that Authority, the Urban Authority shall, within one month after the same has been delivered or sent to their surveyor or clerk, signify in writing their approval or disapproval of the intended work to the person proposing to execute the same; and if the work is commenced after such notice of disapproval, or before the expiration of such month without such approval, and is in any respect not in conformity with any byelaw of the Urban Authority, the Urban Authority may cause so much of the work as has been executed to be pulled down or removed."

. . . .

"(Section 159.) For the purposes of this Act, the re-erecting of any building pulled down to or below the ground floor, or of any frame building of which only the framework is left down to the ground floor, or the conversion into a dwelling-house of any building not originally constructed for human habitation, or the conversion into more than one dwelling-house of a building originally constructed as one dwelling-house only, shall be considered the erection of a new building."

Byelaws in Rural Districts. — Unless special powers have been obtained, byelaws in Rural Districts are confined to such matters as are specified in the Public Health Act of 1890, under which Rural District Councils can, by the adoption of Part III. of the Act, make byelaws as to sanitary and health matters connected with building, such as damp-courses, open space about buildings, ventilation, drainage, closets, privies, ashpits, cesspools, height of rooms, etc. Byelaws relating to these matters are usually based on the Local Government Board's model for Rural Districts, which contain practically no restrictions or conditions as to structural matters, and can be obtained on application to the Council.

Rural Districts with Urban Byelaws. — Under certain circum-

stances, where the development of building in certain parts of the district necessitates stricter control, Rural District Councils may be granted urban powers enabling them to make byelaws as to structure of buildings, etc., similar to the byelaws in urban districts.

Notices and Deposit of Plans.—In all districts in which byelaws are in force notice in writing of intention to build or to lay out a new street must be given to the Clerk or Surveyor, accompanied by complete plans and sections to a scale of not less than 1 inch to 44 feet in the case of streets and block plans, and 1 inch to 8 feet in the case of buildings. The plans must show relative position, level, width, and construction, etc., of streets, and the plans of buildings must show position relatively to streets and other buildings, etc., the level of the lowest floor, lines and particulars of drainage, all appurtenances such as outside closets, cesspools, privies, wells, etc., in addition to the main plans of the building. A description in writing of the materials intended to be used and the intended mode of drainage and water-supply must also be sent. In some districts plans have to be forwarded in duplicate, the duplicate copies being retained by the Council.

Plans having been deposited and the statutory notices given, there is no legal power to prevent building operations proceeding before the Council have approved the plans, which must be given within one month. The Council, however, have power to remove any structure or work done in contravention of the byelaws.

Notices must also be given at completion of any street or building.

Local Acts.—In many of the principal towns in England and Wales special local Acts are in force, either taking the place of byelaws or supplementary to byelaws based on the Local Government Board's model series.

The Acts and regulations referred to in the undermentioned towns give typical examples of the powers relating to buildings possessed by the principal towns, but enquiries should be made as to special or general powers in any case where building operations are contemplated in such towns.

Birmingham.—Local Acts are in force as follows: The Birmingham Corporation Consolidation Act of 1883 and the Birmingham Corporation Act of 1903, which deal with streets and buildings; but the majority of the building regulations are covered by general byelaws.

Bristol.—Building regulations in Bristol are governed by the Bristol Improvement Acts of 1840 and 1847 byelaws, the Public Health Acts of 1871 and 1896, the Bristol Corporation Act of 1905, the Public Health Act of 1907, and the Public Health Act of 1875 and amending Acts.

Fees are payable by the builder or owner to the surveyor of the district according to a schedule both for new buildings and alterations and additions to buildings. There are other provisions as to ownership of party walls and general provisions as to the structure of buildings and projections, cornices, porticoes, verandahs, and other details.

The Bristol Improvement Act of 1847 provides for extension and amendment of the powers of the 1840 Act, and includes regulations as

to the width of new streets, as to buildings and party walls, and gives power for the reduction of fees payable under the former Act.

The Bristol Corporation Act of 1905 provides for additional powers as to streets, and includes a definition as to what is to be deemed a new building.

Cardiff.—There is a Corporation Act of 1894 in force which deals with various matters connected with building operations and streets, including the structure of ovens and furnaces, but the general building regulations are in the ordinary byelaw form made under the Public Health Acts of 1875 and 1890.

Leeds.—The Leeds Corporation Consolidation Act of 1905 includes several matters governing new streets, sewers, buildings, and sanitary matters, but the majority of the regulations are contained in the ordinary series of byelaws.

Liverpool.—The majority of the building regulations are contained in the following local Acts: The Liverpool Building Act of 1842, the Liverpool Sanitary Act, 1846 (as amended by the Liverpool Sanitary Amendment Acts of 1854 and 1864), and the Liverpool Improvement Act of 1882, which includes most of the building regulations in force.

The Liverpool Corporation Act of 1889 contains further building regulations, and there are a few byelaws with respect to new streets and open spaces about buildings.

The Liverpool Corporation Act of 1902 deals with width of streets in certain cases and other street details, and height of chimneys, and the Liverpool Corporation Streets and Buildings Act of 1908 deals with streets, building lines, etc.

Manchester.—There are a number of local Acts here from 1844–1909 containing regulations as to new streets and buildings. The majority of the regulations are covered by the usual byelaws.

Sheffield.—The principal building regulations here are contained in byelaws made under the Public Health Acts and the Sheffield Corporation Act of 1900.

Byelaws under the former Act are of the usual type, covering streets, structure of walls, foundations, roofs and chimneys, open space about buildings, drainage of buildings, sanitary matters, height of chimneys, and height of buildings and chimney shafts. Under the latter Act the byelaws relate to the quality of materials with which new buildings shall be constructed; to the manner in which and the materials with which grates, stoves, and fireplaces shall be set in new buildings; to water-closets and waste water-closets, and the description or nature, size, materials, position, and level thereof, and the apparatus for and the manner of flushing the same, and the means to be provided for protection of the same from frost.

SCOTLAND

For general purposes building regulations come under (1) the Burgh Police (Scotland) Acts, 1892–1903, and (2) the Public Health (Scotland) Act of 1897.

The 1892 Act contains schedules giving rules as to the structure and sanitary requirements for buildings, and applies to all burghs in Scotland except Edinburgh, Dundee, Aberdeen, Greenock. These have special Acts containing similar provisions to those in the general statutes.

The 1897 Act applies to District Committees, County Councils, and Rural Districts, and empowers the making of byelaws regulating the structure of buildings, etc.

In general scope these regulations and byelaws are very similar in effect to those in force in English urban and rural districts.

Local Acts.—The character of the powers possessed by the principal towns in Scotland is illustrated in the two subjoined paragraphs.

Edinburgh.—The legal regulation of building operations in Edinburgh is under the control of the Dean of Guild Court, composed of members of the Town Council and independent experts elected yearly forming this administrative body.

The building regulations are governed by various local Acts from 1879–1913, and are in broad terms, giving general discretionary powers to the Dean of Guild Court.

Glasgow.—Buildings, streets, and sanitary regulations are governed by the Glasgow Building Regulation Act of 1900, as amended by the Glasgow Police Acts of 1866–1899, relating to streets, sewers, buildings, and including byelaws made under the Act of 1900. The Acts deal with new buildings and alterations of any new or existing buildings, streets, plastering, damp courses, damp walls, projections, floors, roofs, lighting and ventilation, chimneys, hearths and stoves, protection against and exit in case of fire, and sanitary and other details.

IRELAND

The building law in Ireland comes principally under the Public Health (Ireland) Act of 1878 and closely follows the general powers in England.

Local Acts.—Some of the larger towns in Ireland have Local Acts dealing with special building regulations, as instanced below.

Dublin.—The powers here are principally under the Public Health (Ireland) Act of 1878 and the Public Health Amendment Act of 1890. The byelaws are similar to the byelaws in England which are based on the urban model code.

Belfast.—The building regulations are made under the Public Health (Ireland) Act of 1878 and various local Acts. Byelaws as to new buildings, etc., are made under the Belfast Improvement Act of 1878 and the Public Health (Ireland) Act of 1878. Alterations of buildings come under the Belfast Corporation Act of 1911.

CHAPTER II

SITES AND FOUNDATIONS

By H. V. Lanchester, F.R.I.B.A.

BUILDING SITES

Selection of Site.—The first step to be taken preparatory to building operations is the selection of a site, and as on the wisdom of such a selection much will depend, the architect should always be prepared to give a well-considered opinion when called into consultation. A few special cases are here cited as an indication of the kind of consideration that should be given to the selection of a site.

Warehouses and factories, more especially those where heavy goods are dealt with, should have easy access to rail or water, or both, according to the character of the business.

Offices and shops usually occupy sites previously allocated, but where this is not the case, as in the lay out of new estates, the selection of convenient positions, with due regard to the probable traffic routes, will require study.

Hospitals, schools, and other institutions should be situated with due regard to the inclination of the ground, preferably south or south-east, and the character of the subsoil, water-supply, and drainage.

Suburban and country houses involve considerations of similar character, although here more latitude can be given as to aspect, it being permissible to design such a house with any aspect from south-east to west, and even a more northerly outlook may be justified by an exceptionally fine view.

Another consideration not to be overlooked in making a selection is the relative cost of building as influenced by the foundations that will be required, the land drainage, the price of material and its carriage. Assuming, however, that a site has been already selected, other important considerations need to be studied. A general examination of the site should first be undertaken, note being made of its contours, general slope, aspect, position and extent of water and springs, particulars of adjacent roads, railways, drainage, and properties, with the object of judging how the site may best be utilised for the particular building which is to be erected upon it.

Trial Holes and Borings.—Before any building is commenced, trial holes should be dug or, in cases where very heavy weights are to be imposed, trial borings should be made. From such holes or borings

at various points on the site can be ascertained the nature, depth, and slope of the underlying strata, and the presence of hidden water and its level.

Levelling. — Sites may be required to be cleared and levelled, and quantities of loose earth deposited, for which, over large areas, special arrangements would have to be made. It is necessary to make a survey, with careful sections taken in various directions throughout the site, while in some instances contours will be useful. The sections should also indicate the depths of the trial holes or borings, and give the nature of the strata encountered. The survey will determine finally the direction of the means of access and roads, the governing floor levels of the buildings, the arrangement of the drainage system, and will regulate the amount of excavation necessary for the most economical levelling of the surface, and the best positions for depositing and spreading the surplus earth.

Bearing Power of Soil. — Knowing the nature of the soil on which the building is to rest, the next step is to determine its bearing power as an index to the loads that can be placed safely upon it, or to the means that must be taken to make it safe (see p. 15).

The question of foundation-beds requires the most careful consideration, as it is usually owing to the failure of these, by unequal pressure or by scour, that the greatest damage is caused to structures. A good foundation-bed should possess the following qualities:

(1) Uniformity of material.

(2) Its surface (except where piles are used) should be at right angles to the pressure upon it.

(3) It must be incompressible or equally yielding throughout.

(4) It should not be affected by atmospheric influences, which cease to operate at a depth of from 2 feet to 6 feet, according to the nature of the soil.

KINDS OF SOIL

1. **Rock.**—It is safe to build to any weight required upon hard rock or solid chalk, and it will usually be sufficient to level roughly the foundation-bed and to make good all cavities or fissures with concrete.

2. **Rock and Soft Soil in Conjunction.** — A foundation-bed consisting partly of rock and partly of some softer substance needs careful attention, as the latter will yield more readily than the former, causing unequal settlement and consequent damage to the structure. This difficulty can be overcome by arching over the soft portions, using sunk piers of concrete or the adjoining rock as abutments, or by driving piles. The safest way, however, would be to form a concrete raft over the whole site.

3. **Gravel.**—This makes an excellent incompressible foundation-bed. The scouring action of water may need to be guarded against, although seldom likely to occur. Gravel is not affected by the action of the atmosphere.

4. **Chalk.**—Varying in its degrees of hardness, chalk can in some cases be regarded as equal to rock, but if subject to the action of numerous springs it becomes soft. Means should therefore be taken, before building upon chalk, to drain it of all water.

5. **Clay.**—Compact hard clay will carry very heavy loads, but running water must be kept from under and around it, and it must be guarded from the action of the atmosphere by fairly deep excavation. Clay is liable to shrinkage and expansion of bulk, caused by the alternate action of the dry and wet seasons, which make this a somewhat dangerous material to build upon unless proper precautions are taken.

Care in Drainage.—Care must be taken in draining that the clay is not dried to such an extent as to cause shrinkage.

Precautions against Heat and Frost.—Where the foundation is less than 6 feet in depth, it is advisable to provide against damage by heat and frost by placing a concrete platform or pavement around the outer walls of the building at ground level, as indicated in Fig. 1, to prevent variations of temperature from penetrating to the foundation.

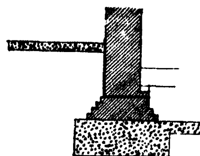


FIG. 1.

6. **Sand.**—If confined laterally and kept free from running water, sand will carry heavy loads.

7. **Quicksand and Silt.**—These are the most treacherous soils upon which to build, and the greatest precautions must be taken to confine them and to provide against the scouring action of water. They are usually so confined by means of sheet piling (see p. 24).

8. **Hard Stratum upon Soft Soil.**—A hard stratum lying upon a softer one will sometimes carry considerable loads, spreading the pressure over a large area. It is safer, however, in such cases to employ piles. If it is decided to build upon the hard stratum, care must be taken not to cut through the crust or in any way to tap the soft material below.

9. **Very Soft Soils.**—Where the ground is very soft to a great depth various methods may be employed: (1) A reinforced concrete raft may be laid over the whole site. (2) A wide trench with good concrete in it may distribute the weight sufficiently. (3) Short piles may be driven over the site of a building and for some distance outside it to consolidate the soil, a foundation-raft being formed upon the piles.

10. **Soft Soil upon a Hard Stratum.**—Method (3) may also be employed where soft soil overlies a hard stratum. The piles should be driven until they are supported by the hard material. An alternative method is to excavate and form concrete piers resting upon the hard stratum.

Preparation of Site and Preliminary Operations

Drainage and Surface Dressing.—Before any building operations are commenced, the site should be made as dry as possible and water drained away or diverted, permanent drains being provided, if necessary,

for this purpose. The top soil should be removed, the roots of trees grubbed up, and disused wells filled in or properly closed. Old drainage systems should be removed or, if this is not practicable, stopped up with concrete.

Utilisation of Old Foundations. — Any old foundations on the site should be carefully examined and used again if suitable. Great expense was saved at Westminster Cathedral by using old foundations found on the site. Unless they are in the way of new work, old foundations may be left, provided they do not interfere with the continuity of the new ones.

Cutting Roads. — If roads or carriage-ways are included in the scheme, it is advisable to cut these and lay hard core before commencing to build. This will permit materials to be brought upon the site, and will be economical, as less handling of materials will be necessary, while the hard core road-bed will be consolidated by the traffic.

Compliance with Byelaws.—Before proceeding with the foundations, the local byelaws must be studied and provision made for their observance. Reference should be made to Chapter I. for information on this subject.

Covering Ground with Concrete.—Generally it will be found that under all domestic buildings the whole ground surface must be covered with a layer of Portland cement concrete or lime concrete, and usually it will be found that the thickness of the concrete for this purpose and the proportions of the materials are specified.

Building direct on Ground.—The byelaws state also the nature of the ground on which it is permitted to build direct and the nature of the damp course.

Low-lying Ground.—In some parts of the country the byelaws indicate the level to which low-lying ground must be artificially raised to form a stable and healthy substratum, or alternatively require the building to be raised upon walls or legs of concrete, brick, or stone, so that the lowest floor of the building shall be of the required level above ordnance datum.

Filling in Trenches.—Before trenches are filled in, the local authorities require notice, so that their surveyor may examine and approve the bottoms, and similar notice before the footings are covered in. Failing the receipt of any notices which are required, the byelaws empower the surveyor to uncover or pull down any work, so that it may be seen that the byelaws have been observed.

Footings.—In most cases the byelaws require footings to project on each side of a wall, " to be at least equal to the thickness of such wall at its base," and describe the nature of the offsets in the footings.

Footings required even where unnecessary.—When building on concrete rafts footings are often unnecessary, but no byelaws recognise this, and no such exception is made. In course of time, as byelaws become amended, it may be that Local Authorities will be empowered to assent to the omission when proper application is made, but in the meantime the unnecessary footings must be formed, however strong the raft which spreads the weight of the superstructure. The London

County Council will, however, grant a special dispensation when satisfied that the mass of concrete is equal in every direction to the footings and concrete prescribed.

Building on Made Ground in London.—In the London County Council area no building is allowed on any site filled in or covered with refuse. Building sites must be covered with concrete 6 inches thick; concrete under walls must be not less than 9 inches thick, and must be 4 inches wider than the footings on each side. In the case of gravel the concrete may be omitted with the approval of the district surveyor. The proportions of lime concrete must not exceed 1 part of lime to 6 parts of ballast, and of cement concrete 1 part of cement to 8 parts of ballast.

TRENCHING

Setting out.—The levels of the site having been taken, the setting out of the foundation trenches is done by pegging out on the ground, offsets being taken from the axial lines in the case of large buildings, the angles of the building being properly squared, and the centre lines and widths of the trenches marked. The whole must be carefully checked before further progress is made.

Boning Trench Bottoms.—To ensure the foundation-beds being level, before the trenches are commenced the erection of *sighting rails*

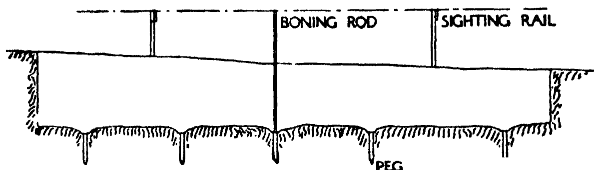


FIG. 2.

at the end of each length of trench becomes necessary, with the rails truly lined up and levelled (see Fig. 2). The excavation then proceeds, and as a sound bottom is approached boning rods are employed. The tops of these *boning*, or measuring, rods are brought to the same level as the sighting rails, and the exact depth of the trench marked off on them, the trench being excavated at intervals to the exact depth required, and tested by means of the rods. Exactitude is obtained by driving pegs in the trench bottoms to agree with the levels fixed by the boning rod, and the earth is cleared away to a true level between the pegs.

Benching.—In cases where it is not practicable to excavate to the same level over the whole site—for instance, where the site is on a slope or where basements and cellars are required under a portion of the building, it is necessary to form the trench bottoms in *benches* or steps upon which to build the foundations.

Drainage.—Trenches must be kept clear of subsoil water or storm water by means of catchpits or by pumping.

Concreting.—Concrete must not be thrown into the trenches from any height, as the coarser aggregate is likely to go to the bottom,

and the best results are obtained from concrete of uniform composition throughout. It is best just to tip the concrete in, and immediately go over it with a rammer to consolidate it. The concrete should be allowed to mature as long as possible before being subjected to heavy loads.

Keeping Records of Concrete.—In large operations it may be necessary to keep careful records of the concrete, as it is deposited in the trenches, for testing purposes. Samples should be withdrawn from the batches as they are mixed, cast in 6-inch to 12-inch cubes, and dated. Subsequent tests on these cubes will give information as to the nature and strength of the concrete at any point in the foundation.

Settlement.—To prevent unequal settlement owing to inequality in the number of bed joints in stone walls at varying levels, the concrete should be carried up as high as possible, while large stones should be used in the lower portions of the wall to reduce the number of joints. Where the walls are of brick, the base should be built of hard bricks in cement mortar.

Filling in Trenches.—As the walls rise and the vertical damp coursing (if any) is applied, the trenches should be filled in with dry rubbish well rammed.

FOUNDATIONS

Design of Foundations.—The design of foundations is dependent on many considerations, such as the nature of the soil, the weights to be borne and their distribution, the advisability of using rafts, with or without reinforcement, or one of the several forms of piling described later, the use of inverted arches, the cutting out of pockets or pot holes in the foundation-bed and the insertion of concrete legs, and the support of adjacent buildings. The designer must always remember, however, that the two main factors in determining the adequacy of a foundation are the natural resistance of the foundation-bed and the loads requir to be spread over it. Concrete laid over the site should be designed to have sufficient rigidity in itself to bridge over any small defective area caused by a settlement or shrinkage in the subsoil, and the proportions of cement to aggregate should be such that the strength of the concrete shall be adequate to support the weights brought to bear upon it without crushing.

Causes of Failure.—It is not always easy to determine the cause of failure in structures, but in many cases defects may be traced to the failure of the foundation-bed. Nevertheless, failures have been attributed to this cause and discovered subsequently to have resulted from settlements originally due to the lack of true machining in the bed and connexion plates of steel stancheons, which, being heavily loaded, have consequently canted slightly on their bedplates and set up fractures in the fabric.

Among the many causes of failure may be mentioned: pockets in the subsoil, the withdrawal of subsoil water (by reason of well-sinking, the

construction of sewers, or the formation of railway cuttings), poor concrete and uneven settlement caused by lack of proportion in the foundation. Unless safe precedents are available for guidance, tests by actual loading should be made, not necessarily at great expense; and with a building designed in accordance with the results obtained, failure need not be feared.

It must not be forgotten that the unseen portions of a building below ground are of the greatest importance, and are to be as carefully considered and designed as the more evident superstructure.

Loads to be supported.—The loads to be supported should be spread over a greater or less area, according to the nature of the soil which carries the building.

Safe Loads.—The following safe loads on soils, concrete, brickwork, and stone must not be exceeded in buildings erected under the jurisdiction of the London County Council (General Powers) Act, 1909, Part IV.:

	Per Sq. Foot.
Natural bed of soft clay or wet or loose sand	1 ton
Natural bed of ordinary clay or confined sand	2 tons
Natural bed of compact gravel, London blue clay or chalk . .	4 ,,

The pressure on concrete foundations should not exceed 12 tons per square foot.

The pressure on any brickwork should not exceed the following:

	Per Sq. Foot.
Blue brick in cement mortar	12 tons
Hard brick (including London Stock) in cement mortar . .	8 ,,
Ordinary brick in cement mortar	5 ,,

The loads on the following stones should not exceed:

	Per Sq. Foot.
Granite	45 to 60 tons
York stone	20 tons
Portland stone . . .	16 ,,
Bath stone	8 ,,

R.I.B.A. Tests on Brickwork.—With regard to the loads on brickwork in cement allowed by the London County Council (General Powers) Act, 1909, it is useful to note that the tests made by the Royal Institute of British Architects in 1895–97 give much higher values, and where heavy loads are to be carried and excellence of workmanship can be assured, there is no reason why the L.C.C. loads should not be exceeded safely, at any rate outside the County area. The R.I.B.A. tests were as follows:

	Loads at which slight defects appeared. Per Sq. Foot.
Blue Staffordshire bricks in Portland cement . . .	53 tons
Flettons ,, ,, . . .	33 ,,
London stocks ,, ,, . . .	29 ,,

Complete failure took place as follows:

	Per Sq. Foot.
Blue Staffordshire bricks in Portland cement . . .	139·52 tons
Flettons ,, ,, . . .	54·88 ,,
London stocks ,, ,, . . .	39·24 ,,

Thus, allowing for an ample factor of safety, it will be seen that in view of the exhaustive tests of the R.I.B.A., the L.C.C. loads err on the side of safety.

Proportions of Foundations.—The designer must arrange that the foundation-bed shall be proportioned to suit the varying weights imposed on it by different parts of the superstructure, so that the pressure shall be evenly distributed in uniform loads over the supporting area. For instance, great weight brought by a heavily-loaded stancheon direct on to the foundation, or the weight brought by a tower, must be distributed until it is spread over a sufficient surface to reduce the load per square foot of area until it is no greater than that borne by the surface under lighter parts of the structure.

KINDS OF FOUNDATIONS

Extended Foundations.—Extended foundations are employed where it is desirable to spread the loads to be borne over a wide bearing surface. In the cases of all soils, except rock, hard chalk, and gravel, the area of the base of the walls should be extended by the use of concrete to keep the pressure per square foot within safe limits. The methods of extending foundations are many, but the more usual forms of them are described in the following paragraphs.

Stone.—Stone walls should be extended on the concrete in the foundations with offsets of from 6 inches to 12 inches, while the courses should be formed of large stones to reduce the number of joints, in order to limit the amount of settlement, and to provide strength where the loads are heaviest.

Brick.—Brick footings should spread on each side at least half the width of the wall they are to carry; that is to say, the bottom course of footings will be twice the width of the base of the wall. The offset of each course should not exceed 2¼ inches, while the lowest projection should be two courses deep. Further particulars regarding brick footings will be found in Chapter VI.

Concrete.—The bearing of both stone and brick footings may be extended by means of wide courses of stone, but the usual course is to extend on concrete filled into trenches. Where the soil gives good resistance, the width of the concrete need not greatly exceed the greatest width of the footings. In London it must not be less than 4 inches on each side, but on poor-resisting soils it may be necessary to extend the width considerably, so that the weight is borne over a wide surface, in which case the depth of the concrete must be at least half the width. Concrete is largely used in conjunction with steel, as in the case of steel grillages embedded in concrete for protection of the metal, and of reinforced concrete foundation rafts.

Steel and Concrete Grillages.—Steel may be employed in grillages under walls to spread the weights over wider surfaces. Short joists should be laid on the concrete at frequent intervals at right angles to the length of the wall, and longitudinal joists upon them to distribute the

weight uniformly. Concrete should be filled in around the joists and to a level about 2 inches above them, the footings being built in the ordinary way.

Grillages under Piers and Stancheons.—Where it is desirable to extend the weight at the foot of a pier or stancheon over an area exceeding that of a stone template (about 5 feet square), steel grillages may be employed, as shown in Fig. 3; the grillage consists of steel joists placed on the concrete bed in two tiers, each tier in a direction at right angles to the one below it. The joists are filled in with concrete between the flanges, and after the stancheon has been placed in position, plumbed, wedged, and bolted, the grillage and base of the stancheon should be covered with concrete.

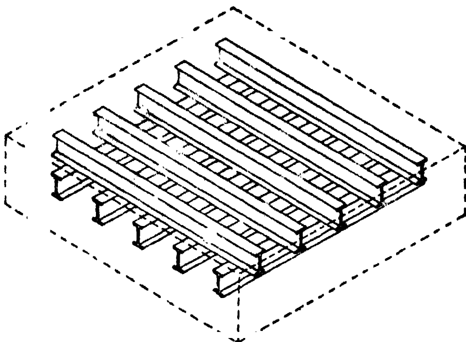


Fig. 3.

Reinforced Concrete Rafts.—For foundation rafts reinforced concrete is a suitable material, especially where it is required to extend concentrated loads over a large bearing surface. Each raft must be designed to suit the individual needs of the structure. In cases where the bearing power of the soil is uneven, the design of a raft requires special care, and it may be necessary to drive piles generally over the site before forming the raft. In making the calculations for a reinforced concrete raft the conditions may be regarded as exactly similar to those obtaining in the case of a loaded floor, only inverted, the beams or areas between the weighted portions having functions similar to those in a floor with a distributed load transmitting these weights, except that the transmission is upward instead of downward. Foundation rafts are often constructed of concrete and steel I-beam or other rolled sections instead of the forms of reinforcement employed by reinforced concrete specialists.

For details as to reinforced concrete construction, the reader is referred to Chapter XIV.

Inverted Arch Foundations. — Inverted arches, described and illustrated in Chapter IX., are employed in foundation walls where it is desired to spread concentrated loads equally over the foundation bed. They are only needed where great weights are brought upon a soft foundation and are placed beneath the openings in the walls above, the intermediate piers acting as inverted abutments.

Cantilever Foundations. — Cantilever foundations are sometimes employed where it is impossible to extend the foundations beyond the boundary line of the site, or where it is necessary to avoid some obstruction, previously existing, upon which it is undesirable or impossible to put weight.

In a case in New York the side walls were built up to the boundary lines, beyond which the foundations could not project, as the adjoining building was also built to the boundary and to a much greater depth. The new building was of the steel-framed type, with enclosing walls, the frame comprising four rows of steel columns, one row in each side wall and two intermediate rows. The weight on the columns in the side walls was carried back to a continuous reinforced concrete foundation beam parallel to, and a short distance inside, the side wall by means of cross beams running from the two inner lines of columns, and extending through the parallel beam in the form of reinforced concrete cantilevers.

Another case, also in New York, embodies a similar arrangement, but in this instance the cantilevers were formed of steel beams embedded in concrete.

Foundation Piers.—Where foundations do not require to be carried to great depths, excavations may be made at intervals to the solid substratum and filled with concrete. The piers thus formed carry the main concrete which is to support the building. This concrete may be formed into arches between the piers, or may be reinforced with steel rods or joists.

Cylinders and Well Foundations. — Hollow cylinders of brick, concrete, iron, or steel can be sunk to great depths, where soft soils have to be pierced, and carried down to the solid bottom. Sinking is done by clearing out the material from the interior of the cylinder, and adding weight to the cylinder to cause it to sink against the friction of the soil. The shaft of the cylinder must rest on a timber or steel frame splayed to form a cutting edge, wide enough on its upper surface to carry the superimposed rings, the cylinder, if of iron or steel, being lined with brick (Fig. 4).

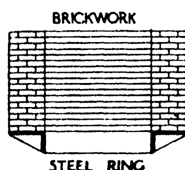


FIG. 4.

Wells very similar to the cylinders described are much used in India and the United States. The shafts are sunk as open wells, lined with grooved and tongued boards and braced internally with steel hoops made in two halves, the ends of each half bent inwards to form flanges for the connecting bolts. In India the method employed is almost the same as that described for the cylinders. The masonry is built up on a wooden curb to a height of some 3 or 4 feet; this section is then undermined and sunk to its depth in the ground, when another section is built, the structure being again undermined, and so on until the required depth is reached. The masonry must be of first-rate quality and the undermining performed evenly all round, or the work may crack in consequence of excessive strain. In all cases the shafts of both cylinders and wells must ultimately be filled with concrete.

Cylinder and well foundations are not often employed in this country, their use being generally restricted to works where support is required for heavy wharf walls and similar structures. In most cases piling is preferable.

Open Caissons.—An open caisson (Fig. 5) is a water-tight com-

partment or box, open at the upper end, and can be constructed on the bank of a river, then floated into position and sunk by the weight of the masonry pier built inside. The bottom consists of two or more layers of heavy timbers laid at right angles to each other and bolted together. The sides are strongly framed and secured to the bottom by long bolts,

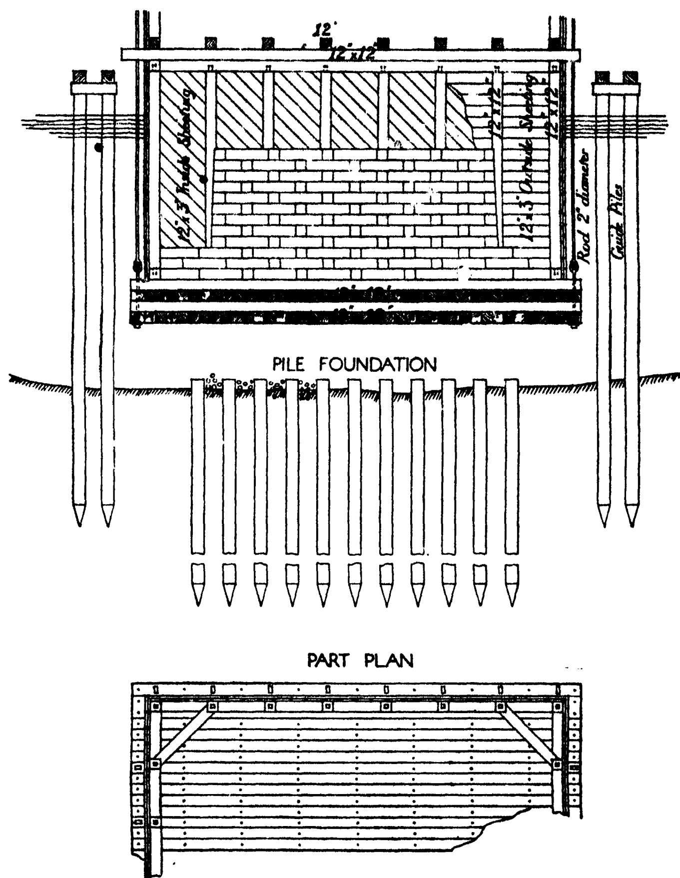


FIG. 5.

to ensure a water-tight joint and to provide for the subsequent removal and re-use of the sides.

Before the caisson is floated into position a few courses of the masonry are laid as ballast. When in position, the building of the masonry is continued until the caisson is nearly sunk. The caisson is then adjusted over, and allowed to settle upon, its bearings; and on completion of the masonry the bolts are released so that the sides of the caisson may be raised for use elsewhere.

Pneumatic Caisson.—The pneumatic caisson consists of a chamber of any suitable shape or size, upon the top of which a masonry pier is to be built. The chamber is open at the bottom, but air and water-tight elsewhere, and is sunk in the same way as a cylinder. Compressed air is employed to force out the water in order that excavations can be made from the interior. The working chamber in which the compressed air is contained must be air-tight, so that in order to maintain the pressure special arrangements have to be made for access to and egress from the chamber. This is done by means of an air-lock, in the form of an air-tight box with upper and lower doors, which must open towards the pressure of the air, and when shut must close against rubber-lined rebates in order to obtain a proper seal. An air-tight steel shaft is built into the caisson for the passage of the workmen, and is connected with a shaft formed in the masonry of the pier as work proceeds. The air-lock is situated at the junction of the steel and masonry portions of the air-shaft. Auxiliary shafts are provided for the supply of concrete used in filling the working chamber on the completion of sinking, as well as a shaft for the removal of earth, or pipes for the discharge of mud and sand. All auxiliary shafts must be fitted with air-locks in order that the working pressure may be maintained.

Freezing Process.—This has been used with advantage in building foundation piers in quicksand. Pipes, one inside the other, are sunk through the sand to the hard strata below. The pipes are arranged round the area of the part to be excavated, and are connected to a cooling tank at the top. Freezing liquid is pumped through the inner pipe, returning through the outer pipe to the cooling tank, where, after being refrigerated, it is again circulated. The liquid has the effect of freezing the soil around each pipe until a frozen wall is formed, the central portion of the area being partly frozen. The centre is then excavated, leaving a sufficient thickness of frozen crust to resist the surrounding pressure. As excavation proceeds, the sides are additionally secured with framed sheeting, although in small shafts this may not be required, as the frozen material will resist the outside pressure. It is essential that the freezing process should be maintained continuously until the foundation work has been completed.

Injected Cement. — Another method of treating quicksand to convert it into a solid mass is by the injection of cement grout. Pipes are sunk into the material at regular intervals, and a current of water is forced through them, causing a cavity to be scoured out at the foot of the pipes. Into this cavity a fluid mixture of Portland cement and water is forced through the pipes. By using pressure the cavity is filled, and the surrounding material is also impregnated and solidified. The pipes are then raised and the process repeated. The pipes are provided with valves to shut out upward currents, and care must be exercised to prevent them from being set in the hardened material.

Pile Foundations. — Piles are now made in so many forms and applied in so many different ways in building construction that it has been found desirable to discuss them and their application in the following sub-section.

PILES AND PILE FOUNDATIONS

Bearing Piles. — Bearing piles are employed to support vertical loads. They are driven or sunk into the ground until a hard stratum is reached, or until the friction on their sides provides sufficient resistance to enable them to carry the required load. Bearing piles are usually formed of wood, steel, concrete, or reinforced concrete. Short piles are sometimes driven into soft soil to consolidate it by lateral compression, a foundation raft being formed on the head of the piles.

Pile Driving.—Pile-driving machines, or engines, of various kinds are used. In the types most largely used a heavy weight is raised and allowed to drop upon the head of the pile. Machines of this class can be driven by manual, animal, or mechanical power as may be found most convenient. The well-known principle of the steam hammer has also been applied to pile driving, the engine being in portable form so that it can be suspended over the head of the pile to be driven. Piles can also be driven by the water-jet method, where the operation is facilitated by the erosive action of water at the foot of the pile.

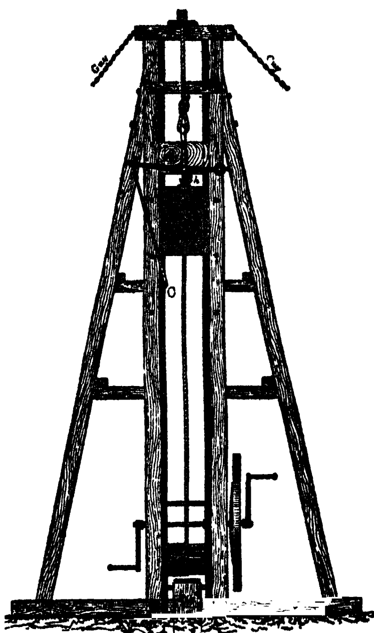


FIG. 6.

Falling-weight Machines.—Fig. 6 illustrates a simple form of machine, worked by manual power and suitable for driving. It consists of an upright lead, side braces, and guy ropes. The cast-iron weight, or *monkey*, weighing about 250 lb., is guided in its descent by wrought-iron or steel straps, and is attached to a rope running over a pulley block at the top of the lead. The free end of the rope is made with several strands upon which the men may haul. The monkey is raised some 3 or 4 feet, as far as the men can conveniently reach, and allowed to drop upon the top of the pile, the men taking advantage of its rebound to tighten the slack rope. In this case the rope is not detached from the monkey, which is caught up on its rebound by means of a trigger attached to the leads, thus saving labour to the men in raising the weight the full distance.

Horse-power is used in the following manner: The rope is attached to a capstan fitted with a long lever arm to which a horse is harnessed, and as the capstan is revolved the rope is wound about the drum, causing

the monkey to rise, until at the proper moment the capstan is thrown out of gear and the monkey falls.

Pile-driving machines of the falling-weight type can be operated by steam or internal combustion engines, electric motors, or hydraulic power, the rope being wound around a drum and the weight allowed to fall at the proper time by releasing a catch. This method is rapid, and the engineer in charge can regulate the exact length of the blow as required.

Steam-hammer Machines.—Pile-drivers of the steam-hammer type are employed economically where a large number of piles have to be driven or very heavy blows are required. The hammer takes the form of a heavy ram attached to a piston rod which works in the steam cylinder, and rises and falls rapidly, delivering as many as seventy blows a minute, thus effecting a great saving of time and labour.

Water-jet Method.—When it is required to drive piles to a con-

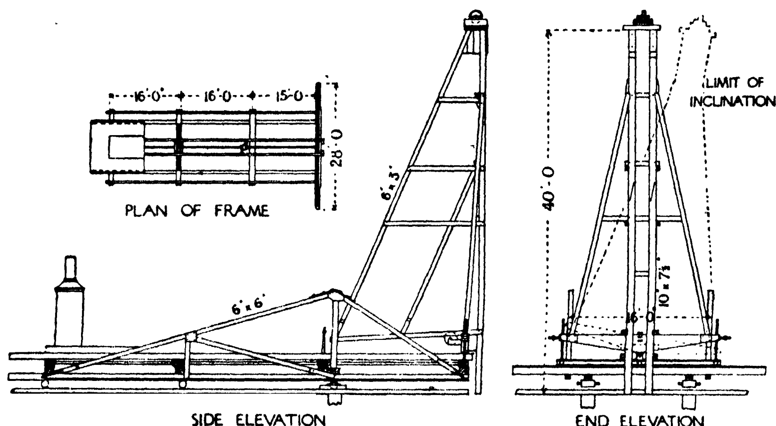


FIG. 7.

siderable depth through soft material without heavy blows, which might cause damage to the pile, the water-jet method is adopted. A groove is usually cut in the pile and a 2-inch pipe inserted, with a nozzle at the point of the pile. Water is forced through the pipe by means of a force pump, loosening and removing the soil about the foot of the pile, which can then be sunk by light blows from a monkey, or steam hammer, or by a weight placed on the head of the pile. By this method piles have been sunk in sand from 20 to 25 feet in two minutes.

Driving Inclined Piles.—To drive inclined, or *raking*, piles, leads are pivoted to a strong steel or wooden frame (Fig. 7) that can be tilted by means of ratchets and screws, allowing the leads to be inclined to any angle at will. The pile is then driven in the ordinary way, the hammer falling between the leads to the head of the inclined pile.

Protection of Pile Head in Driving.—To obviate bruising and splitting during the operation of driving, timber piles are usually chamfered for 2 or 3 inches from the top, and the head fitted with a strong iron band.

A preferable method of attaining the same end is to employ a cast-iron hood or helmet fitting over the head of the pile. Pile-driving hoods are sometimes made with a recess to receive a cushion of hard wood at the top; otherwise, a short piece of timber, termed a *dolly*, must be placed above the hood so as to absorb the shock of the weight or hammer.[1]

In driving reinforced concrete piles a hood is almost invariably used, the interior space being partly filled with sand or sawdust as a cushion. The monkey used in pile driving for timber piles should be slightly concave (to a depth of about 2 inches) on its lower surface. This will round the top of the pile head after a few blows, fitting it closely to the hammer, and to some extent will tend to prevent bruising or splitting.

Bearing Power of Piles.—Piles support the loads over them by reaction at the point of the pile and by the frictional resistance set up between the surface of the pile and the soil with which it is in contact. The following formula may be used to determine the safe load which may be put on a pile: $W = ra + R$, in which W = the safe bearing strength of the pile, r = the resistance caused by the friction of the soil on the faces of the pile, a = the area in square feet of the faces of the pile in friction with the earth, and R = the safe resistance to settling determined by the bearing strength of the earth. The value of r in various soils may be taken as follows:

	Lb. per sq. foot of Surface of Pile.
Close hard sand or gravel	500 to 600
Mixed earth with gravel and sand	400 „ 500
Hard clay	200 „ 250
Soft clay or silt (semi-fluid)	150
Silt or quicksand	(No value)

The value of R is usually known, and may be taken from the table on p. 15, varying from 2240 lb. per square foot in soft clay or loose sand to nearly 9000 lb. per square foot in gravel or London blue clay. The value of a in a 9-inch by 9-inch pile would be 3 feet super per foot of length in contact with the soil.

Depth Necessary.—The depth to which a pile will require to be driven may be found thus: Assuming that each pile has to carry a uniformly distributed load of 15,000 lb., and that for hard clay the value of $r = 225$ lb., then $a = \frac{W - R}{r}$, or about 47 square feet of pile surface. Consequently a pile 9 inches square would require to be driven about 16 feet into the soil.

Strength as a Column.—While considering the depth to which a pile should be driven, its strength as a column must not be overlooked when it is to project above the ground. The safe load per square inch of sectional area of the pile (according to the material of which it is formed) and its length as a column should be taken into account. The sectional area of the pile must also be considered in the case of piles which do not project above the ground. The area provided must be sufficient to support the loads brought on to them without crushing.

Tapering Piles.—By driving tapering piles small end downwards their bearing area and frictional resistance will be increased. Some

authorities advocate driving butt end downwards, so that the timber occupies its natural position, but this is unusual and is wasteful as regards timber. Moreover, it is doubtful if the increased bearing area at the butt is as great as that set up by the tapering sides of a pile driven with the small end downwards, and certainly the frictional resistance will not be so great as in the case of tapering piles.

Testing Bearing Power.—A pile should not be further driven when, after a reasonable test, it has refused to go farther, as overdriving merely causes damage to the fibres (Fig. 8). Such a test may be made by erecting a platform on a series of the piles when driven, and loading to twice the weight required to be carried. If no settlement occurs, the piles may be assumed to be safe and sufficiently driven, but if settlement does occur, then longer piles will be required or additional piles must be driven. A single pile may be tested by loading it until settlement takes place, the result furnishing data from which the number of piles required can be gauged. Such tests should not be made too soon after the piles have been driven, about two days being allowed for the soil to become solid round the pile.

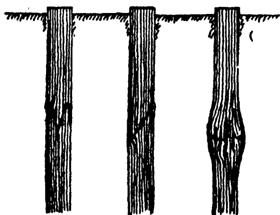


FIG. 8.

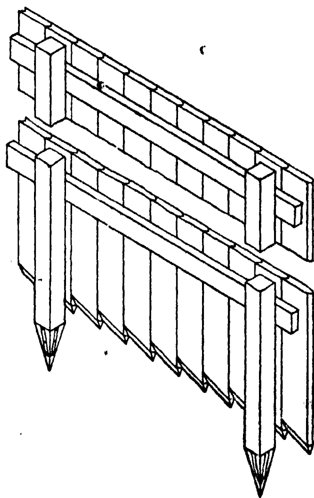


FIG. 9.

Sheet Piles. — Formed of wood, steel, concrete, or reinforced concrete, sheet piles are used to enclose the area of a foundation so as to prevent the soil from spreading laterally, or to protect it from the action of water. Sheet piles of timber may either butt, or should be grooved and tongued, or be bird's-mouthed, the latter being most general in good work. In the case of steel and reinforced concrete sheet piling, special methods of jointing are adopted as described later. Sheet piles are splayed at the lower end (as in Fig. 9), with a cutting edge shaped so that it tends to close each pile up to that previously driven. The cutting edge is protected by a strip of steel nailed to the narrow edges of the pile, or preferably by a properly made steel shoe.

Applications of Sheet Piling.—The following particulars, illustrating two familiar methods of utilising sheet piles in building construction, may be taken as applicable to all piles of this type, whatever may be the material of which they are made.

Consolidation of Soft Soil.—Sheet piles can be employed where it is required to confine soft soil for the purpose of increasing its bearing power, and to prevent the lateral escape of the soil under the pressure brought to bear upon it. Guide piles are first driven at the angles of the site to be enclosed, with intermediate guide piles between the angles as often as may be necessary—usually about 7 feet apart. These ordinary piles are left projecting from 2 to 3 feet above trench bottom, and to them two pairs of stout waling pieces are fixed, the lower pair to form a sill at trench level and the upper pair to form a sill at the head of the piles. The waling pieces in each pair are spaced far enough apart to allow the sheet piles to pass when being driven, but no more. Between these the sheet piles, each about 11 inches by 3 inches, are driven, the walings acting as guides and keeping them perpendicular in direction.

The site having been confined by this means, ordinary piles may then be driven within the enclosure at regular intervals in order to solidify the soil, the whole area being afterwards covered with a concrete raft.

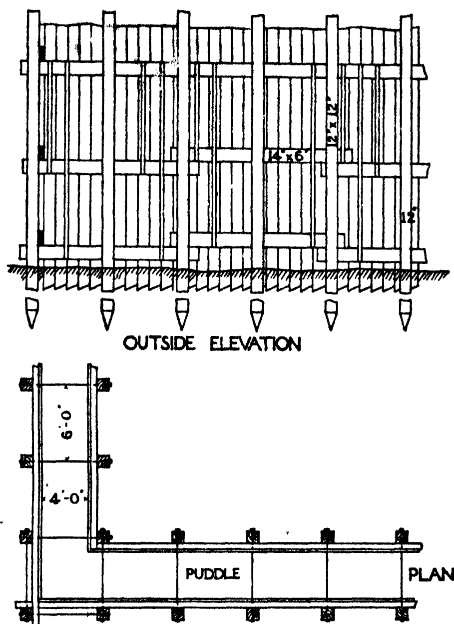


FIG. 10.

Cofferdams.—Cofferdams are constructed where it is necessary to enclose an area below the water-level, in order to be able to pump it dry for building purposes. Timber sheeting was formerly employed exclusively, but steel sheet piling is now largely used. Concrete and reinforced concrete are obviously unsuitable for temporary construction such as a cofferdam. The method of construction may be thus briefly described: Guiding piles are driven in two rows to enclose the space within which the work is to be performed, the enclosed area being greater than the area of the proposed structure, so as to allow room for working (Fig. 10). The piles should be driven about 8 feet apart, and the distance between the rows of piles should be about 6 to 8 feet, according to the height of the dam required above the bed-level. Waling pieces are fixed at intervals in the height of the piles from the bed-level below water to the top of the piles. The rows of piles are bolted together by means of iron rods tying the piles opposite each other in the two rows. Sheet

piles are then driven in each row, close together and guided by the waling pieces, the piles penetrating below the bed to prevent the water from finding its way underneath them. Each sheet pile when driven is spiked to the waling pieces. The space between the two rows of sheet piling is filled in with puddled clay, which should be well rammed with a pointed ram to prevent the clay from forming in layers. On completion, the cofferdam can be pumped out and work commenced within the enclosure.

Timber Piles.—Timber piles are lengths of timber, squared or unsquared. Various kinds of timber are used, including oak, pine, fir, cypress, elm, and Australian hardwoods. Oak will stand driving better than pine or cypress, but cannot be obtained in such long lengths and is more expensive, while cypress does not stand driving so well as pine. Pine, which is most generally used in building work, can be obtained from 90 to 100 feet in length, with diameters up to 18 inches at the butt and up to 12 inches at the top. Before use the small end of the pile is stripped of bark and the end pointed. A wrought-iron band about 3 inches wide and ¾ inch thick is placed round the top to prevent splitting and *brooming*, a broomed head forming a cushion which reduces the effect of the blow. The top of the pile should be cut true, or on driving there will be a tendency for the pile to get out of the perpendicular. Piles which are to be driven through hard materials should have a steel shoe attached, as shown in Fig. 11; this is usually a solid metal point from which straps extend for fixing to the pile, the fixing being best done by means of coach screws or large clout-nails. The shoe protects the lower end of the pile from injury, besides facilitating the operation of driving.

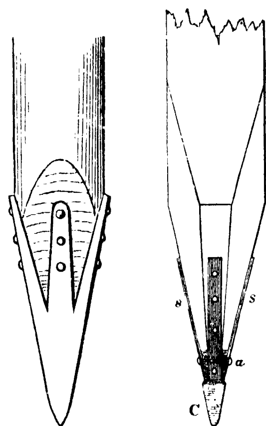


FIG. 11.

The bearing power of piles varies from about 6 tons to 70 tons, according to the size, kind of timber employed, and the nature of the soil.

In sand and gravel, piles will carry to the full loading capacity of the timber used, if driven deep enough for the end of the pile to escape vibration and scour. The depth of 10 feet will usually suffice. Piles driven 30 to 40 feet into swampy soil will carry, by frictional resistance alone, 10 tons or more, while piles driven into stiff clay will support loads of from 20 to 40 tons per pile.

Cutting off under Water.—Piles often require to be cut off below water-level, and to do this it may be necessary to employ professional divers. Sometimes to avoid the heavy expense thereby involved, the piles are cut off by saws actuated by machinery from above.

Steel Piles.—Steel piles may consist of any convenient structural sections, or built up to the required sectional form. They are driven

in the ordinary way, with a dolly or cushion of timber to receive the blow of the monkey. Extra labour in cutting the head of the piles to a level is involved.

Steel Sheet Piles.—Steel sheet piles may be built up to any suitable section and driven with the plates overlapping. After driving they may be bolted together through the adjoining flanges.

Concrete Piles.—These piles are advantageous in places where timber piles are liable to decay owing to alternations of wet and dry conditions. There are many forms of concrete piles, which may be of any convenient size, either square or circular, about 15 inches across.

Piles Moulded in Advance.—Concrete piles of this kind are cast in moulds, and, after sufficient time has been allowed for the concrete to mature, are driven in the ordinary way, with a timber cushion or driving hood over the head to receive the blow of the monkey, the point of the pile being fitted with a steel shoe.

Piles formed "in situ."—Concrete piles to be constructed *in situ*, either in earth or water, are moulded in a cylinder of wrought-iron or steel, with a detachable iron or cast concrete point, driven in the ordinary way, the stroke being received on a timber cushion or driving hood. The cylinder is afterwards filled with concrete, and gradually withdrawn, leaving the point behind. A fresh point is then attached and the cylinder used again.

Reinforced Concrete Piles.—Reinforced concrete piles are of many kinds, and may be moulded before being driven, or formed in place in a similar manner to that described above. The chief advantage of reinforced as well as plain concrete piles is their immunity from decay and corrosion. Their disadvantages are that they are heavier to handle than timber, and that they cannot be floated into position for works in water.

Piles Moulded in Advance.—For piles of this class the cross-section may be circular or square. The main reinforcement usually consists of four or more vertical round steel rods from ¾ inch to 2 inches in diameter, tied in place with lateral reinforcement in the form of horizontal links or a winding of steel wire. The point of each pile is fitted with a steel driving shoe, having lugs turned inwards to form a secure junction with the concrete.

Piles formed "in situ."—Reinforced concrete piles may be formed in position by the use of the steel casings, as described for plain concrete piles, and the reinforcing rods placed in the sheath before the concrete is filled in. The reinforcement may be of the customary kind, or may take the form of an expanded metal cylinder inserted within the outer casing before the concrete is added.

Piles with Extended Base.—Another type of reinforced concrete piles is formed with an extended base or footing, as represented in Fig. 12. After the cylinder is in position (no shoe points are employed in this case), the earth is bored and washed out to an additional depth. A cambering machine, which when closed will pass through the cylinder, is then inserted. When pressure is brought to bear upon it, this machine expands,

and being twisted loosens the earth at the bottom, which can then be washed and pumped out. After withdrawal of the machine the reinforcement is placed in position and the concrete deposited and rammed. The enlarged base thus obtained gives many times the bearing area of an ordinary pile.

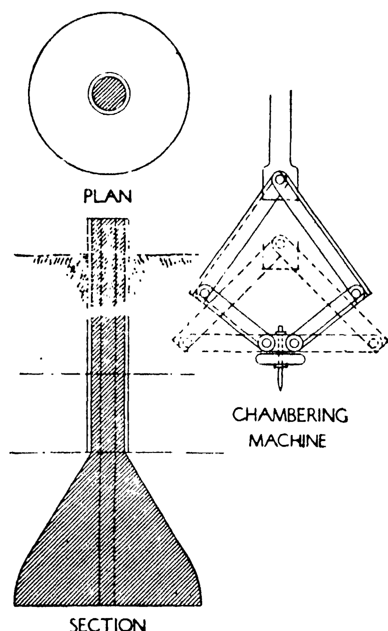


FIG. 12.

Sheet Piles.—Reinforced concrete sheet piles are rectangular in shape, with extra reinforcement in the long sides, while the shoe is shaped like a wedge at the bottom and splayed off longitudinally to form a cutting edge. Sheet piles are sometimes formed of I-section steel joists or pairs of I-sections plated together at intervals and cast into the concrete.

All sheet piles are grooved at the sides in order that a watertight joint may be made by grouting and circular holes may be left in them, with an outlet on each face near the foot, so that the water-jet method (see p. 22) may be applied to assist in the operation of driving, or so that thin grout may be introduced into the surrounding soil.

Screw Piles.—Screw piles may be of wood, iron, steel, or reinforced concrete, having a screw at the end, and may be turned into the earth by hand or power. When the piles cannot be screwed farther without signs of twisting in themselves, and it is required to go deeper, the water-jet method can be used in the same way as described for timber piles.

Screw piles of timber have a cast-iron screw at the lower end. It is important that such piles are not damaged in their fibres by over twisting.

Large screw piles are usually hollow and of cast-iron or steel, circular in cross-section, with a wide flat screw at the base, which cuts into the material and increases the bearing area of the pile. These piles are driven in sections, extra lengths being added to the top as the lower lengths become embedded. Small screw piles are made of solid wrought-iron, mild steel, or cast steel, the screw being of cast-iron (Fig. 13).

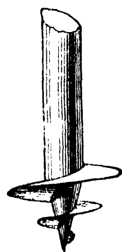


FIG. 13.

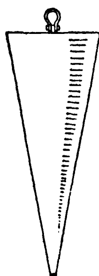
Reinforced concrete screw piles are made with helical reinforcing rods, continuing throughout the entire length of the pile to withstand the strain set up by the operation of screwing down the pile. Further

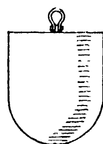
reinforcement is introduced to add to the compressive strength of the pile by minimising lateral expansion due to axial compression. Tubes can also be cast into the pile for the use of the water-jet, and a cast-iron shoe may be affixed as in other kinds of piles.

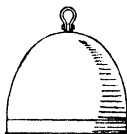
Screw piles may be usefully employed where it is desirable to avoid the vibration and shock due to the blows of the monkey, or hammer, employed in driving ordinary piles.

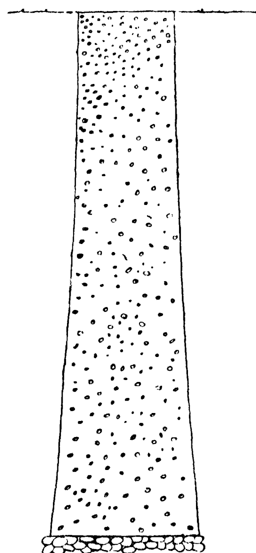
Disc Piles.—Disc piles are somewhat similar in nature to screw piles. Instead of the pile having a screw on the lower end, a flat disc is attached, in order to spread the bearing at the base of the pile, which is sunk by means of the water-jet.

Compressed System of Piling. — The "compressol" system was introduced into France some years ago, and, as its name implies, is a method by means of which the soil is compressed. Rams are dropped on to the earth, in a similar manner to the monkey, from a pile-driver, except that in this instance the machine used has no leads or guides, and the ram is dropped clear to the ground without friction. These rams, which are of various shapes, form a deep hole in the ground for the construction of concrete pile. The first ram, or *borer* (Fig. 14), is about 6 feet long, weighing about 30 cwts., and is conical in shape. It falls with its pointed end downwards. This pointed end pierces the earth, and has a cavity in its apex that gathers a sample of the earth it penetrates, which may be examined after each stroke. The height of the fall is varied according to the soil to be pierced, and the operation is continued until the hole has been sunk to the required depth. The sides of the hole are so strongly compressed that no supports are needed to keep the earth in position. The second ram, or *rammer* (Fig. 15), about 3 feet long, is then substituted, and is used to punch down large stones placed at the bottom of the cavity. This rammer forces the stones outwards and spreads the base of the cavity, which is then filled with concrete in layers, which are pursued with the third ram or *tester* (Fig. 16), weighing about a ton, so that the concrete shall be compact and solid, and


FIG. 14.


FIG. 15.


FIG. 16.


FIG. 17.

the cavity completely filled. The result is a concrete pile with an irregular surface and an enlarged base (Fig. 17), spreading the weight over a wide area. A raft can be formed bearing on all the piles so made. It is claimed for this method of piling that it has been proved efficacious in a large number of buildings, and that it is a means of effecting large savings in the cost of excavation.

Sand Piles. — Sand piles are employed occasionally for supporting light loads where the soil is soft, without being wet or fluid. A wooden pile is driven and withdrawn, the hole left being filled with sand, which is well rammed. This operation is repeated at intervals of about 3 feet, and where the sand is well filled the result is a good foundation. Sand piles possess the advantage that the weight is transmitted to the sides as well as to the bearing area in a somewhat fluid manner, the sand, if well rammed, filling in and gripping the sides of the hole. The piles are covered with concrete in the usual manner, which prevents the sand from being squeezed upwards by lateral pressure. In very loose or wet soils, sand piles are not advisable, as they might be scoured out by the action of subsoil water.

CHAPTER III

TIMBERING EXCAVATIONS, SHORING, AND UNDERPINNING

BY PROFESSOR C. H. REILLY, M.A., F.R.I.B.A., AND
PATRICK ABERCROMBIE, M.A.

TIMBERING EXCAVATIONS

IN excavating for foundations or drains, the ground is frequently so firm and the excavation so shallow that a simple trench will suffice, the sides of which need no support. But if the soil is at all loose or the cutting more than 4 or 5 feet deep, support will be necessary for the sides, varying according to the nature of the soil. This support is afforded by timbering, the main factors being horizontal, and occasionally *raking struts* wedged against the sides, their reacting thrusts being distributed to such extent as necessity may dictate.

In sinking vertical shafts, provision must be made for raising the earth from the bottom of the shaft, and for guarding against the telescoping of the side sheeting.

Timbering to Trenches.—In the subjoined notes particulars are given relative to the timbering of narrow, wide, and deep trenches, but it must be understood that the various methods described are capable of modification and combination as desirable, to comply with individual requirements and local conditions.

Narrow Trenches.—The timbering of narrow trenches, for foundations, or drain laying, which have usually a minimum width of about 3 feet, varies much according to the nature of the soil.

In moderately firm soil rough vertical planks called *poling boards* are placed against the sides of the trench at intervals of about 6 feet apart, when it has been excavated to a depth of 3 to 4 feet. The boards are wedged apart by struts of a scantling from 4 to 6 inches square. The poling boards are somewhat shorter than the depth of the trench, and the struts, usually not less than two in number, are placed against them about 2 feet apart vertically. The safe interval between the boards is naturally determined by familiarity with the nature of the soil. The struts are sometimes round, being made by cutting up old fir scaffolding poles. The material in timbering, as in all temporary work, depends on what the builder happens to have handy, and strengths for this reason are often far in excess of actual requirements.

In looser soil the method shown in Fig. 18 becomes inconvenient owing to the closer spacing of the poling boards and the larger number of struts required. To obviate interference with work, a third system of timbers should be introduced. These, known as *walings* (W, Fig. 19), run horizontally in front of the poling boards, and the struts are

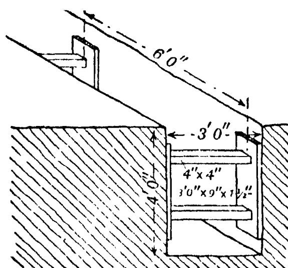


FIG. 18.

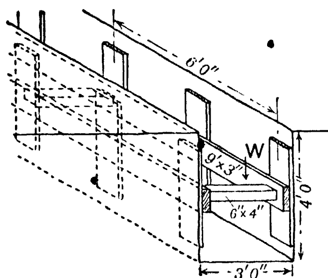


FIG. 19.

wedged between them. The distance apart of the struts depends on the strength of the walings, but is usually about the same as for moderately firm ground (about 6 feet), and in any case each strut naturally comes opposite a poling board. The distance apart of the latter depends entirely on the soil. They may be so far apart that only one occurs in each 6-feet length between the struts, or so close together as practically to form continuous vertical sheeting (Fig. 20). Again, in shallow trenches (up to about 4 feet deep), one waling running along the middle of the poling boards would probably be sufficient, but for deeper trenches walings are necessary at top and bottom of the poling boards. The scantling of all members varies, of course, in proportion to the width of the trench and the pressure upon its sides. The walings should never be less than 3 inches thick, 9 inches × 3 inches being average dimensions, and the poling boards should be about 1½ inches thick. It is not necessary for the walings to be scarfed, as absolute continuity is not required; their ends need not meet, but the struts, placed near the end of each, come close together, the poling boards being spaced out regularly.

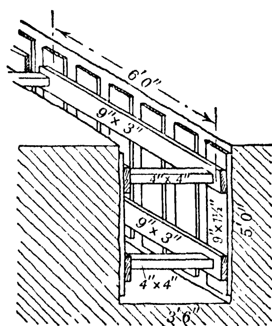


FIG. 20.

In the case of a loose surface over a firm subsoil it is sometimes necessary to timber the upper part of a trench, the lower part of which is cut through rock or shale. In this case the best way is to use a single pair of walings, and struts without poling boards, as shown in Fig. 21.

In very loose soils, such as running sand or slipping clays, instead of using vertical poling boards placed side by side, it is more convenient

to line the trench, as in Fig. 22, with horizontal boards or *sheeting*. With these it is possible to support the sides of the trench while excavating to a depth of not more than 1 foot at a time. The method of working is as follows: A portion, from 9 to 12 inches deep, is excavated, and at once supported by planks placed horizontally on both sides and kept apart by struts; then another 9-inch depth is taken out, another plank being placed on each side, below those already in position, and similarly strutted. When the required depth has been reached and, say, five or six planks inserted and duly strutted, vertical poling boards are fixed 3 or 4 feet apart and strutted in the usual way. The struts to the sheeting are then removed. It is usual for such a trench to be of tapering section (Fig. 22), as, if the soil should recede, the struts and poling boards by dropping down would still wedge up tight. If the trench is a deep one, it may be necessary to make the poling board in two lengths, so that the upper half of the

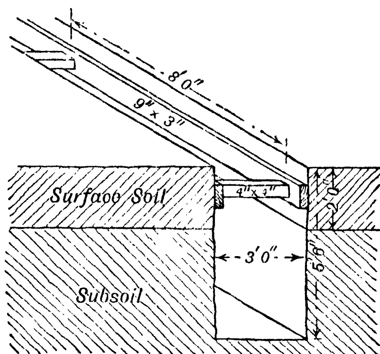


FIG. 21.

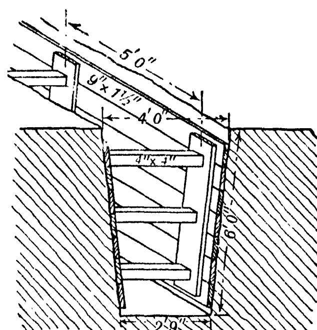


FIG. 22.

depth of the trench may be finished, and the great number of struts (one to each horizontal board) dispensed with before excavating the lower half. The side sheeting and poling boards should be about 1½ inches thick.

Wide Excavations.—Wide trenches through bad ground need strong support before the struts can be wedged in place. This can be supplied by strong guide piles, shod with iron or not according to the hardness of the soil, and driven a foot or more below the required level of the trench. The guide piles being in position at intervals of about 6 to 8 feet, for a trench 20 feet wide (Fig. 23), the spaces between them are filled by sheet piles or *runners*, driven in side by side and forming the sides of the excavation. These sheet piles, 9 inches by 3 inches, have a chisel point, usually shod with thin steel strip, nailed on, and cut slanting or splayed in such a way that as each pile is driven it wedges tight up against its neighbour. As the ground is excavated between the two rows of sheet piling, waling pieces are inserted and strutted apart, both waling pieces and struts being 9 inch × 9 inch whole timbers. As these heavy balks of timber cannot be held in position by the mere tightening of the horizontal

struts, auxiliary supports are necessary. In some instances, cleats or brackets are nailed to the guide piles under the waling pieces, as in Fig. 23; in others, uprights of the same scantling are inserted. Short vertical struts 6 inches by 6 inches are shown in the same drawing as intermediate supports for the horizontal struts.

Raking shores are sometimes used underneath the horizontal struts; in this case they should butt at their upper end against the cleats which support the walings.

Deep Excavations.—In an excavation where one set of guide and sheeting piles will not reach to the required depth, the trench is taken down in stages; the first, to within 1 foot or so of the bottom of the

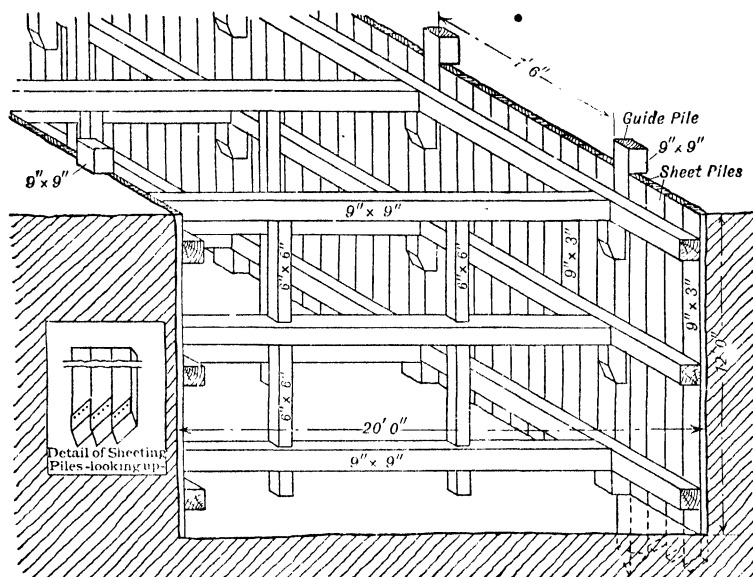


FIG. 23.

sheet piles, and finished off with waling and strutting complete; a second set of guide piles and sheeting is then driven, in front of the first, and exactly the same process is repeated, the trench being carried down and timbered, as in the case of the first stage. The operation is repeated until the required depth is reached, the trench at each successive stage narrowing down a couple of feet or so.

Variety of Treatment.—It may be judged from the examples which have been given of timbering for trenches of different depths and widths, and in different kinds of soil, that a great variety of treatment may be adopted; the use of any method, indeed, will always be modified by local circumstances, and particularly by the timber which the contractor happens to have available. It would be easy to go on multiplying

combinations of members, but probably enough has been said to suggest the wide range of modifications possible. Only one further instance will be given, which would be quite practicable in a type of trench coming midway between those shown in Figs. 22 and 23 by using sheet piles or runners without the guide piles, the walings and struts approximating to those shown in Fig. 20. This modification, illustrated by Fig. 24, may be regarded as a development of the arrangement in Fig. 20, with the poling boards placed side by side, shod with iron, driven 1 foot below the bottom of the trench, and called sheet piles.

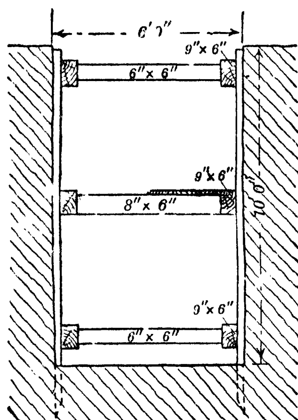


FIG. 24.

Removal of Timbering.—The stage at which it is permissible to remove timbering depends very much upon circumstances, and particularly upon the use made of the trench. Where foundations are being built, the struts can usually be withdrawn when they get in the way of the footings or walls, and replaced by short props wedged between the face of the brickwork and the poling boards. If these props are placed on opposite sides of the wall there is little danger that they will loosen the freshly laid brickwork. If the trenches are for drainage purposes the earth can be thrown in, and the lower range of struts struck as soon as the earth has been rammed tight enough to hold the feet of the poling boards apart. It is not always possible to withdraw all the timbering; indeed, where the ground is bad and the excavations are near the building, it is sometimes advisable to leave piles in, as their removal might cause a subsidence.

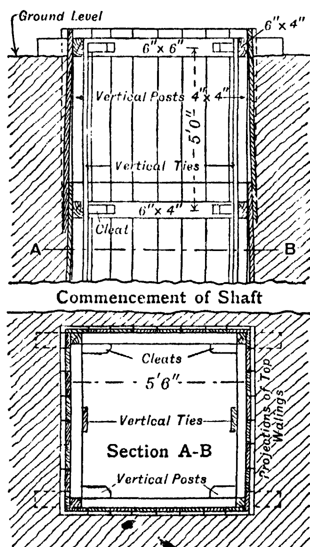


FIG. 25.

Timbering to Shafts. — *Vertical Shafts.*—These are merely short lengths of trenches with returned sides, and if shallow are timbered, in the same way as trenches.

Deep shafts are sunk in a series of stages, the four waling pieces forming frames and the sheeting overlapping. There is, however, a danger in shafting work, owing to the tendency, as excavation proceeds, of the sides to slide down bodily, or for the stages to telescope vertically. This can be prevented, however, by keeping the top

frame of waling pieces above the ground level (Fig. 25), two of the pieces projecting on either side of the shaft, and the others connected to them with vertical ties. The work is completed by posts at the corners.

Wide shafts are constructed with intermediate struts and vertical supporting pieces on exactly the same principle as the wide trenches shown in Fig. 23. A shaft of 10 feet square or more would require to be supported in this way.

SHORING

Definition.—The term *shoring* is broadly used for any sort of temporary support which is afforded by props of timber or other material acting under direct compression. The timbering of trenches is a form of shoring, the struts being short, horizontal, or flying shores, so also is the support of the upper part of walls by *needles*, while the lower part is being rebuilt or removed. But it would be more convenient if the significance of the term *shoring*, in building construction, were limited so as to apply only to methods of temporarily supporting unsafe structures, whose instability is caused either by the removal of adjacent buildings, by faults in construction, or by defective foundations. Shores employed in such methods of support are of three different kinds: (1) *Raking shores*, where the shore is inclined towards the building, one end resting on the ground; (2) *Flying shores*, where another building is made use of for support, and the main shore is horizontal; (3) *Dead shores*, applied vertically, and acting merely as temporary props. The use of needles supported by dead shores in connexion with the rebuilding or the removal of the lower part of walls comes more appropriately under the head of *Underpinning*, which is discussed in a subsequent paragraph.

Avoidance of Shock in Erection.—Seeing that shoring is almost invariably applied to old or unstable structures, it is of the greatest importance that there should be no violent knocking in its erection. When folding wedges are used to tighten up a system of shores, they should be driven home gently, and levering or screwing up should be done by slow degrees.

Raking Shores.—Inclined or raking (Fig. 26) shores usually consist of balks of timber, one end resting upon the ground and the other pressing against the wall at the point where the outward thrust is considered to be greatest. It is clear that the more nearly horizontal is the angle at which the shores are inclined against the wall, the more direct is the push against the wall. An angle of 45 degrees would probably be the most effective, but in practice the inclination is generally much steeper, owing to the difficulty of obtaining sufficiently long timbers, and to the limited space which is generally available.

Triangular Framing.—In a building divided up into stories, it may reasonably be taken that each story and the roof constitute points where the outward thrust is concentrated. Consequently, it is necessary to oppose a shore at each of these several points. Instead of being carried parallel down to the ground, these shores are united at the foot into a

single triangulated system, the third side of the series of triangles so formed consisting of a vertical member or *wall plate* held against the wall. This plate has the additional advantage of distributing the actual thrust of the shoring against the wall, thereby preventing any of the shores from loosening or forcing a hole through the brickwork of a decayed structure. Viollet-le-Duc pointed out the superiority of the triangular form of frame, which is seen at its simplest in a system of two-shores. The strength of the frame can be further increased by strutting the shores together with planks nailed across them (as at *a*, Fig. 26), these being particularly necessary at the middle of the shore, where there is a tendency for the member to bend inwards.

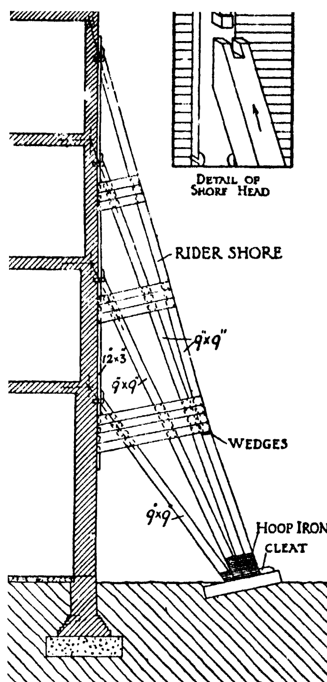


FIG. 26.—A system of four Raking Shores.

The shores are secured to the sole piece by means of iron dogs for the inner shores, with the addition of a cleat to the outermost shore. The feet are then bound round with hoop iron, and braces in the form of 1-inch planks are nailed across, on both sides of the shores and on the wall plate, with the effect of materially stiffening the whole system.

Shore Head.—The abutment at the head of the shore (Fig. 26) is formed by a *needle*, which is inserted in the wall, a half brick being removed for the purpose. The size of the needle is usually 4 inches by 4 inches, an inch being cut off its depth where it passes through the wall plate and enters the wall. Additional support is given by a cleat, which is nailed above the needle. The shore head is notched as shown, so as to prevent it from shifting laterally, and secured by the insertion of a wedge. The wall plate is secured to the wall by hooks driven into the mortar joints.

In order that the shore head may be in correct relation to the needle, the centre line of the shore should pass through the point where the needle meets the wall plate.

The general position of the shores in relation to the roof and floors is determined as follows: If the floor is solid, the intersection of the centre lines of the floor and the shore should be in the centre of the wall; if there is a wall plate to take the foot of rafters or the ends of joints, the centre line of the shore should pass through the centre of the wall plate.

Shore Foot.—The lower end of each shore rests upon a sole piece, a plate wider than the shore, and long enough to distribute the pressure over a sufficient area of ground (see Fig. 26). It is not placed at right angles to the outermost shore, but somewhat nearer the horizontal, so that by levering the foot of the shores nearer towards the face of the building, the whole system can be tightened up as much as may be required. This tightening must be done with the utmost care by means of a crowbar, working in a slot in the outer shore.

If the ground is not sufficiently firm to constitute a proper foundation, the sole piece must be laid on a raft, or platform of timbers placed crosswise, and of sufficient extent to provide a secure base.

Rider Shores.—In buildings of considerable height, the outermost shore proves of inconvenient length, both as regards weight and fixing, as well as through the difficulty of obtaining sufficiently long timbers. A *rider shore* must then be used, which, instead of resting on the sole piece, stands on a length of timber laid along the back of the second shore. It must be tightened by oak folding wedges at the junction, and secured by timbers (*a* Fig. 26) nailed across the shores.

Flying Shores.—Where buildings stand close together, and particularly in a row of houses when one is to be removed and rebuilt, the most convenient and effective abutment for a horizontal shore can be obtained from an opposite wall. In a terrace it frequently happens that two opposite walls require support, and shores then take the place of the house that has been temporarily removed. The length of such shores does not usually exceed 30 feet, as the bridging nature of the system becomes unwieldy beyond that length; moreover, the horizontal shore should never be jointed, as rough scarfing is not sufficiently strong. The general arrangement of flying shores between two buildings is illustrated by Fig. 27.

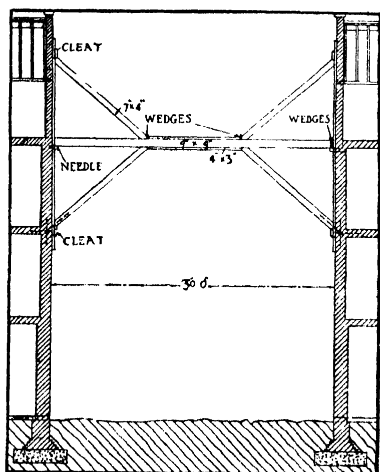


FIG. 27.—Flying Shore.

Method of Construction.—The method adopted in the construction of flying shores is similar to that employed for raking shores. Wall plates are spiked to the wall, which is perforated to take the needles, here merely acting as brackets for support of the shores, the latter being wedged tightly between the wall plates with oak folding wedges. For a narrow space nothing more is necessary, but usually each horizontal member is stiffened with raking struts, one end of each strut butting against a straining piece nailed to the upper or lower side of the shore, and the other ends are confined by cleats nailed to the wall plate, or if

necessary housed into the plate. The struts, therefore, serve to distribute the pressure over the wall. The whole system is tightened up by folding wedges driven between the feet of the upper struts and the straining piece.

Complex Systems.—When the buildings are of great height and of many floors, several main horizontal members must be used, and with their raking struts formed into a complex system. The wall plates in all cases must be continuous, although there is no objection to a halved joint if the length is too great for a single piece. Where the buildings are so far apart that it becomes necessary to erect deep trusses similar in design to trussed partitions, including vertical struts, it will probably be found simpler to use raking shores.

The great advantage, however, of flying shores over raking shores is that they leave the ground free for building operations, this being particularly desirable when a house is being rebuilt between two others. Where the span is great steel shoring can be employed with advantage, obviating the complex trussing of timber flying shores, and the inconvenience due to the feet of raking shores.

Ancillary Raking Shores.—It is frequently advisable to apply *ancillary*, or auxiliary, raking shores at the front angles of buildings which are strutted apart by flying shores.

Dead Shores.—A vertical post of wood, used to prop up any portion of a building, is described as a *dead shore*. A head and sole piece is usually provided to distribute the pressure, and the shores are tightened up by oak folding wedges. They are used in the operation of *needle shoring*, described in the paragraph on Underpinning.

UNDERPINNING

Underpinning consists in rebuilding, either by reason of failure or for purposes of alteration, the lower part of a building without damaging or weakening the superstructure. It may or may not be necessary to employ some form of shoring, either raking or dead, and the characteristic process known as *needling* is associated with one form of underpinning. A *needle* is a beam of timber or steel laid horizontally at right angles to the wall, and supported on props or shores under a wall or part of a building, which it helps to support temporarily while the part below is being underpinned.

Underpinning may be roughly divided into two groups: the rebuilding of foundations and the rebuilding or removal of walls above ground level. Strictly speaking, the same methods may be used for both, but in practice it is found convenient to vary the procedure.

Underpinning Foundations.—In cases where it is necessary to rebuild the foundations without affecting the superstructure of a building, excavations are made on both sides down to the bottom of the foundation, in lengths of 4 or 5 feet at a time, and sections of the brickwork are cut out. If this is performed with great care, the stability of the fabric will not be affected. If the ground is suspected as the cause of failure, it must be excavated until a firm bottom is reached, the hole being filled up with concrete and the new footings built upon the new bed until the

underside of the old work is reached. The brickwork should be laid in cement, and if the new courses do not coincide with those in the old work, the new brickwork can be levelled up by a course of slate. When the new pier, 4 or 5 feet in width, is set firm, a similar section on either side of it may be cut out and rebuilt, and so on until the whole of the foundation has been renewed, the excavated earth being filled in as the work progresses.

In some cases it may be desirable to construct the whole of the new

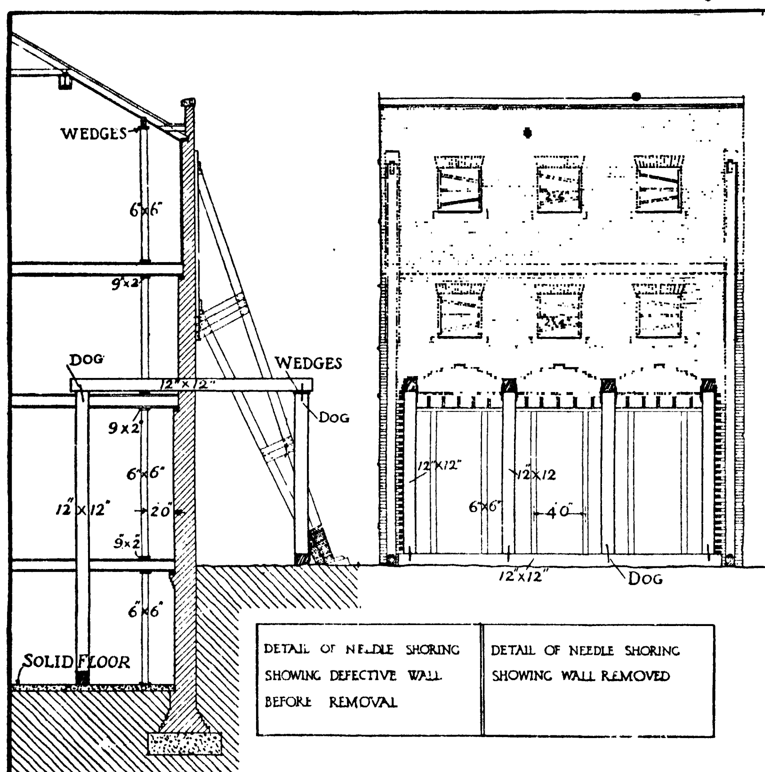


FIG. 28.—Underpinning in order to remove the lower portion of a Wall.

work in concrete, deposited in moulds formed of timber sheeting in the usual way.

Underpinning Superstructures.—For the removal and rebuilding of work above ground, the method used for underpinning foundations would prove too slow, and means must be devised of propping up the upper part of the building, while the whole wall is rebuilt at once. Needle shoring must be employed for this purpose, as shown in Fig. 28. It consists in making holes, not more than 6 feet apart, in the wall above the faulty portion, and usually just above a floor level; through these

eyes are threaded needles, consisting of whole timbers, 12 inches by 12 inches, or steel beams, and supported inside and outside the building by dead shores, dogged to continuous sole pieces, of large scantling. Great care must be taken that the inner sole piece rests on solid ground and not on a suspended floor or the crown of a vault in a cellar. If a single dead shore cannot be taken to a firm bottom inside, the floor or vault must be firmly strutted up directly below the shore. The horizontal needles must be wedged tightly under the brickwork by means of folding wedges driven between them and the top of the outer dead shores, and the whole work dogged together.

Ancillary Shoring.—Before any walling is removed, it is of the utmost importance that ancillary, or auxiliary, shoring should be executed in the form of floor and roof strutting, window strutting, and raking shoring.

Floor and roof strutting, or the dead shoring of floors and roof, precedes the needle shoring, as it is essential to relieve the wall to be underpinned of all weight as far as possible. The strutting should run parallel to the wall, about 2 feet within it, and the struts about 4 feet apart. Continuous head and sole pieces help to receive the weight and prevent a strut which does not come over a joist from pushing through a floor board or ceiling. If the roof is carried by principals, struts to the tie-beam will probably be sufficient; if not, a temporary purlin should be strutted up to relieve the wall plate of weight. The strutting is tightened throughout with folding wedges.

Window strutting consists of small uprights, 4 inches by 2 inches, to each reveal, and three transverse struts which, being cut slightly too long, can be knocked tight. As window openings break the continuity of the wall, they are sources of weakness, and must always be strutted before underpinning is commenced.

Raking shoring is added at discretion, and there is no doubt that if the wall is strong enough to bear it, judicious levering up of the feet will enable the shore to lift a considerable amount of weight off the needles.

Removal and Rebuilding.—As soon as the shoring is in place, the brick walling between and under the needles may be removed to the foundations, and rebuilt up to the underside of the old work.

Insertion of a Girder.—In cases where it is merely required to insert a girder, as for a shop front, in a perfectly sound building, the method of procedure is essentially similar to that already described. The piers to carry the girder are first built in cement, bonded with the old wall, and the girder is fixed in position under the needles. The space between the upper flange of the girder and the old brickwork is then filled in with brickwork in cement.

Striking of Shoring.—Care in the removal of shoring is of the utmost importance; a week at least should elapse before anything is done. The needles are removed first, beginning with the easing of the wedges and the filling of their holes, in order that the wall may settle upon its new support. The floor, roof, and window strutting is next removed, and finally the raking shores. Two days should be allowed between each removal to enable the wall to become gradually accustomed to its new substructure.

CHAPTER IV

SCAFFOLDING

By W. NOBLE TWELVETREES, M.I.Mech.E., M.Soc.Ing.Civ.

IN view of recent legal decisions, the definitions of the term *scaffold* hitherto given in most text-books require to be widened somewhat in scope.

Consequently, a scaffold as employed in building construction may be defined as any temporary erection of timber used to support workmen, structural materials and appliances during the erection, alteration, repair or demolition of buildings, and used where required in connexion with the hoisting, lowering, and distribution of structural materials and appliances.

VARIOUS FORMS OF SCAFFOLDS

Bricklayers' Scaffolds.—Fig. 29 illustrates the construction of an ordinary bricklayers' scaffold. The upright poles, or *standards*, are first erected single or in pairs according to the weight to be carried, the end of the poles being embedded about 2 feet in the ground; in places where the ends cannot be embedded they may be supported in barrels filled with tightly rammed earth or sand. The standards should be spaced from 6 to 8 feet apart, and from 4 to 6 feet away from the building. Horizontal poles or *ledgers* are lashed or otherwise fixed across the standards. The transverse bearers or *putlogs* should be spaced from 3 to 4 feet apart, the outer end tied to the ledger and the inner end wedged into a hole left in the wall. Putlogs are about 3 inches square, and upon them are laid scaffold boards, which should be 1½ inches thick. The safest way of laying the boards is with butt joints, a method requiring two putlogs a few inches apart at each joint. As the building rises, additional poles are lashed or "married" to the standards first erected, and ledgers are added as required at vertical intervals of 5 feet, which is the greatest height at which a man can lay bricks with ease. The ledgers and putlogs used at the lower levels are left in place to steady the scaffold, and in exposed positions, or where the scaffold is more than 30 feet high, diagonal bracing is fixed outside the standards and ledgers.

Masons' Scaffolds.—As putlogs cannot be conveniently inserted in stone walls, masons' scaffolds are formed by erecting two parallel frames of standards and ledgers along the face of the wall, as shown in Fig. 30, where all essential parts of the construction are clearly indicated. In

some cases it may be necessary to add shoring at intervals, as represented. The frames should be from 4 to 5 feet apart, the inner one as close as possible to the wall; the standards should be from 4 to 5 feet apart. For building heavy walls, the scaffold described above is duplicated, so that two parallel frames are on each side of the wall to be built, the frames being connected by ties passing through window openings. If ordinary scaffold poles are not of sufficient strength, the standards are made of square timbers with fish-plate joints, and the ledgers may also be of rectangular section, bolted to the standards. In order to provide for the

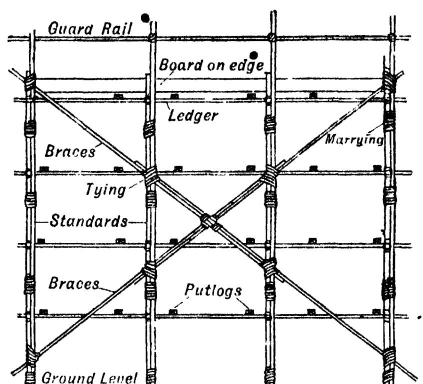


FIG. 29.—Bricklayers' Scaffold.

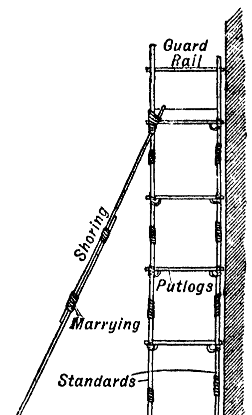


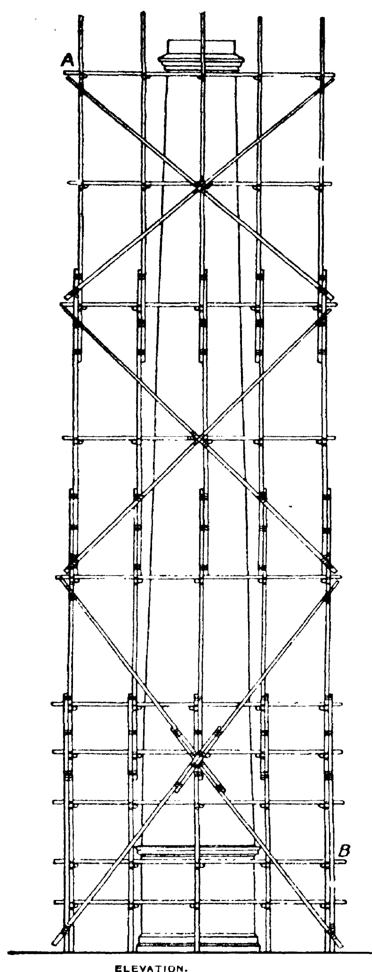
FIG. 30.—Masons' Scaffold.

delivery of materials without infringing upon the space necessary for the work of the masons, an auxiliary platform may be erected, from 5 to 10 feet square, on the outside of the scaffold.

Chimney Scaffolds.—Chimney shafts can be built from internal scaffolding, formed of standards, ledgers, and putlogs, the standards being supported by bearers laid on the internal set-backs of the brickwork. The working platform carried by the putlogs should have a hinged trap-door in the middle for access and the delivery of materials. This system of scaffolding is not to be recommended for chimneys where the brickwork is more than 1 foot 10½ inches thick, as any greater thickness makes it difficult for the men to reach the external joints.

Fig. 31 includes an elevation and two half plans of an external scaffold for chimney shaft construction. The outer standards should be embedded in the ground, and the inner standards placed on sleepers to distribute the weight. The standards should be carried to a sufficient height above the top of the chimney to provide for the support of hoisting tackle and for the safety of men engaged in fixing the cap.

Spire Scaffolds.—Fig. 32 comprises an elevation and two half plans of a scaffold for an octagonal spire. The scaffold is supported by a frame at the head of the tower below the spire, and the successive stages are erected as the work proceeds, beams being laid across the corners of the upper frames, so as to keep the working platform close to the



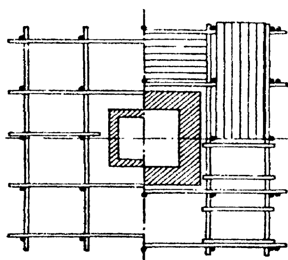
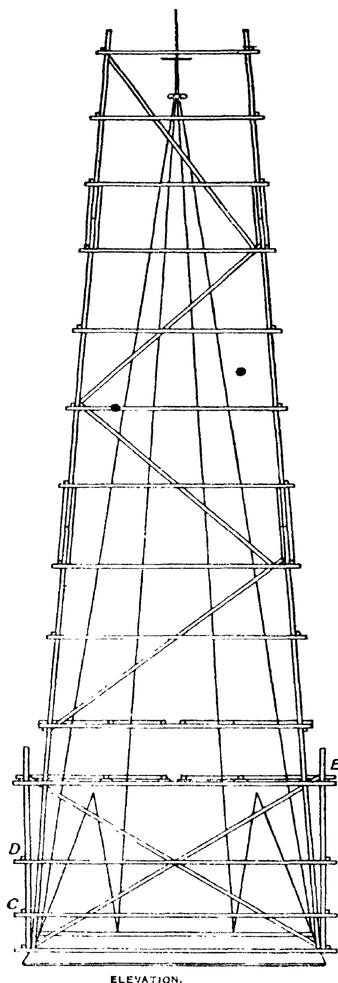


FIG. 31.—Chimney Scaffold.



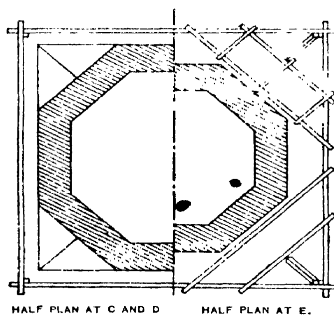


FIG. 32.—Spire Scaffold.

face of the work. The raking standards are shown in three lengths, spliced with fish-plates, one on each side of the standards.

Dome Scaffolds.—The scaffolding necessary for the interior painting and repair of domes, consists of numerous standards rising from ground-floor level. The standards are spaced a few feet apart, connected by ledgers and horizontal braces, and the whole is braced by diagonals, as in the case of ordinary scaffolds. In buildings where it is desirable to keep a considerable proportion of the area free from obstruction at ground level, the number of standards required can be reduced by the liberal employment of diagonal bracing for supporting and stiffening the upper ledgers, on which the working platforms can be placed. Fig. 33 is a diagram representing the scaffold erected for the redecoration of a dome 60 feet in diameter and rising to a height of 85 feet above ground-floor level. The main platform was supported by thirty standards lashed to the balconies, and upon it was built the upper scaffold inside the dome proper.

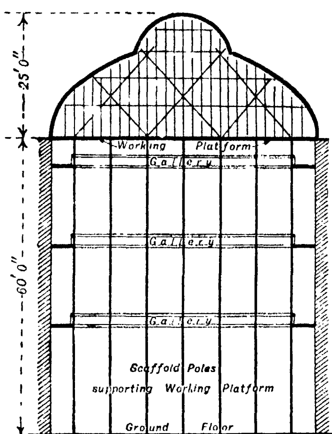


FIG. 33.—Dome Scaffold.

Suspended Scaffolds. — Various forms of suspended scaffolds are employed in the erection, repair, cleaning, and painting of buildings. For example, working platforms can be laid on light framework suspended by ropes or chains from beams placed across the top of a chimney or tower, or from cantilever beams projecting from the upper part of a building.

Another form of suspended scaffold consists of a strongly framed *cradle* or *boat*, fitted with guard rails and boards, slung from fixed supports, or from a wire rope attached to two jibs at some distance apart. This method possesses the advantage of permitting the cradle to be moved longitudinally for a considerable distance without shifting the supports, vertical movement being provided for by means of suitable gear.

Cradles can be obtained of length sufficient for the accommodation of two or more men. In the United States suspended scaffolding, comprising a series of long cradles, has been employed for constructing the external walls of steel frame buildings, the cradles having been suspended from cantilevers projecting from the top of the steelwork, and the cradles connected so as to form a continuous platform.

Saddle Scaffolds.—A saddle scaffold, as required for the repair of a chimney, lantern, or other structural feature situated at the middle of a roof, is formed by erecting standards on each side of the building and carrying ledgers between them over the roof for the support of a working platform. The standards must be strongly braced and shored, the ledgers and upper scaffold being braced by poles carried diagonally across them and secured to the standards.

Needle Scaffolds.—Employed in cases where it would be impracticable or too costly to build scaffolding up from ground level in the ordinary manner, needle scaffolds (Fig. 34) can be conveniently adopted for repairing purposes as well as for erecting the walls of new buildings. The scaffold is supported by a series of cantilever or *needle* beams, passing through window openings or through holes left or cut in the walls. The beams must be carefully proportioned for the weight to be carried, and the inner end must be securely strutted or otherwise held down. In the case of a steel frame building where the steelwork is erected before the enclosing

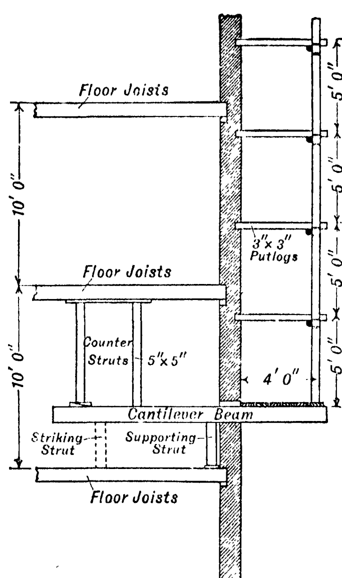


FIG. 34.—Scaffold Needle.

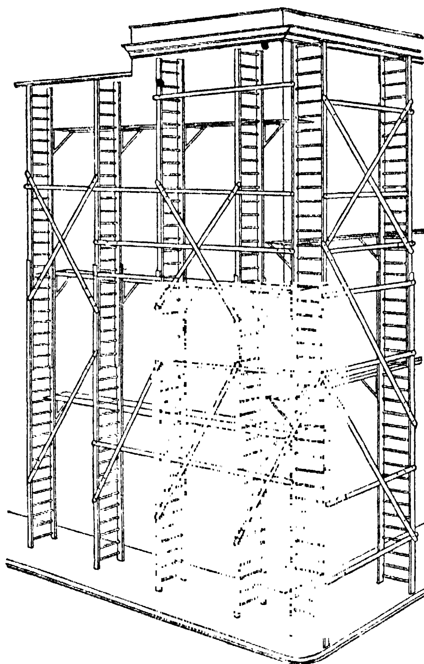


FIG. 35.—Heathman's Ladder Scaffold.

walls, or in the case of repairs to an existing building, the method of strutting represented in Fig. 34 presents no difficulty. But to provide for holding down the inner end of the cantilevers in buildings of which the upper part has not been erected, the cantilevers must be tied down to some immovable part of the structure below.

Ladder Scaffolds.—For painting and other work on the exterior of buildings, ladders are sometimes used in the erection of light scaffolds which can be very easily assembled and taken down.

Fig. 35 illustrates Heathman's patent ladder scaffold, formed of *extension ladders*, with diagonal bracing bolted in position. The ladders are lashed to horizontal bars analogous to putlogs projecting from window openings, and fixed by a jambing arrangement consisting of a stout tube

fitted at one end with a nut in which works a screwed rod. Working platforms are supported on brackets bolted to the inner face of the ladders.

Fig. 36 represents Palmer's patent scaffold, built up of ladders with parallel sides, placed about 10 feet apart and 2 feet 6 inches away from the building. The ladders are connected by horizontals serving the purpose of guard rails, at intervals of 7 feet 6 inches apart, and the whole system is braced by diagonals as shown. Brackets are fixed as represented in the end elevation for the support of working platforms, and the scaffold is tied to the building by horizontal bars secured in window openings by a jambing arrangement.

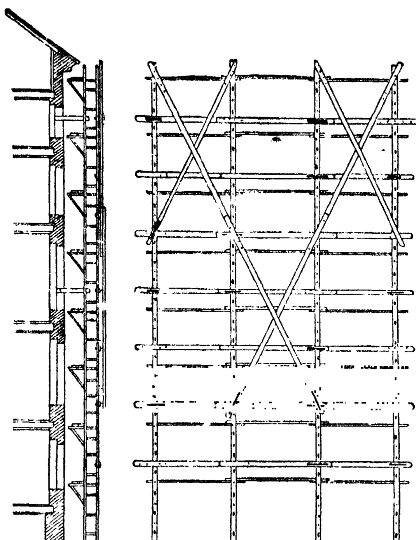
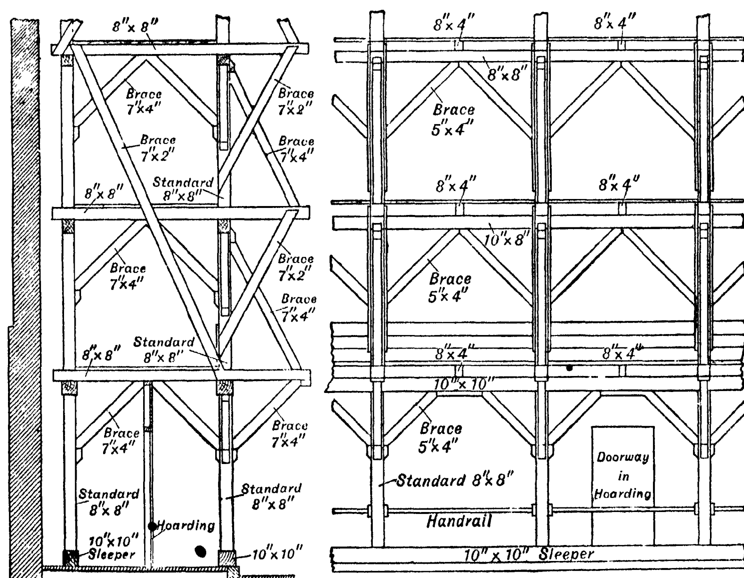


FIG. 36.—Palmer's Ladder Scaffold.



SECTION ELEVATION

FIG. 37.—Builders' Staging.

Builders' Staging.—This is a substantial form of scaffolding, two or more tiers in height, built of square timbers, and securely braced so as to enable the staging to withstand the strains due to the hoisting and handling of heavy blocks of stone, large girders, and other materials. Fig. 37 gives details of a typical builders' staging, on the top of which rails can be laid for a travelling crane if desired.

GANTRIES

The term *gantry* was originally applied exclusively to timber frames carrying tracks for travelling cranes and kindred appliances for handling heavy materials, but is now employed to denote any temporary structure of which one working platform constitutes a base for building operations, or for the support of cranes, scaffolding, or materials. The three principal varieties are Traveller, Platform, and Derrick Tower Gantries.

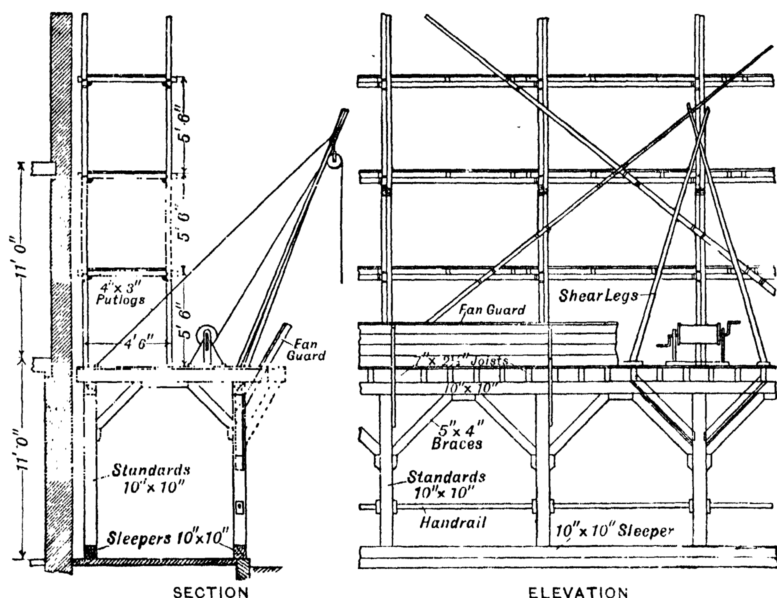


FIG. 38.—Platform Gantry.

Platform Gantries.—A platform gantry is a framed structure finished with a platform for the reception and distribution of materials, and for the support of scaffolding. Fig. 38 illustrates a platform gantry as usually constructed over a footpath which has to be kept open for traffic, the upper scaffold shown being of the masons' type. If materials are not intended to be delivered on the platform, as usually happens where derricks on tower gantries are employed on the works, the fan-guard can be replaced by a hand-rail fixed to posts about 2 feet 9 inches high.

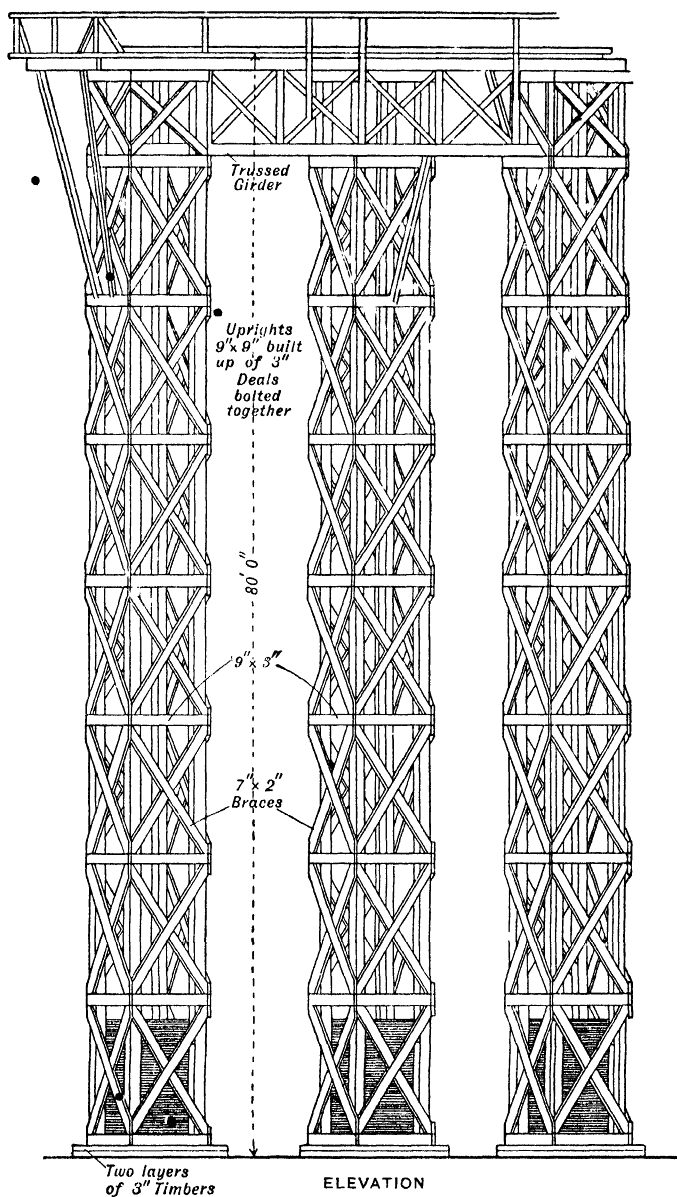


FIG. 39.—Derrick Tower Gantry.

Traveller Gantries.—A traveller gantry is similar in construction to a platform gantry, but the platform is replaced by a movable carriage, or *traveller*, mounted on four wheels running on rails laid along the top of the gantry frame, and capable of being moved from end to end of the latter. The travelling carriage is fitted with rails providing a track for the carriage of a crab or winch, capable of being moved from side to side of the gantry. Thus, by means of the longitudinal and transverse movements, the entire area covered by the gantry can be commanded by the crab or winch. Traveller gantries are made up to 50 feet wide and of any required length, the details of construction varying considerably according to the span and the weights to be dealt with.

Derrick Tower Gantries.—The staging for the support of derricks employed in the construction of large buildings, usually consists of three timber towers carrying a platform upon which the derrick is erected.

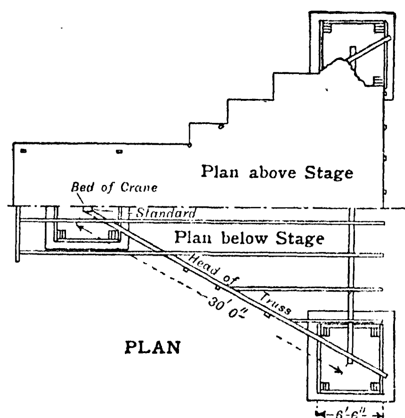


FIG. 40.—Derrick Tower Gantry.

Fig. 39 shows a derrick staging with three towers in elevation, and Fig. 40 gives half plans of the staging, which is 50 feet high, each of the towers being 6 feet 6 inches square and composed of four corner standards, 9 inches square, built up of three 9-inch by 3-inch deals, arranged to break joint suitably and bolted together. The corner standards should be placed upon two thicknesses of 3-inch timbers, unless a concrete or other solid foundation is available, and the standards should be tied at intervals of 10 feet apart vertically by horizontal braces, 9 inches by 3 inches, and braced by 7-inch by 2-inch diagonals. In addition to the corner standards, the crane or *king* tower has a central standard in order that the weight of the derrick may be transmitted directly to the foundation. The other two towers, called *anchor towers*, are provided with strong chains carried down from the crane stays to ring bolts in the foundation, with the object of guarding against any overturning tendency on the part of the gantry. The foundations should be loaded with bricks or other convenient material to a weight not less than double that of the greatest load to be lifted, plus the weight of the derrick jib. The anchor towers are connected by beams for the support of the platform, and each anchor tower is connected with the king tower by a deep trussed girder. In the case of very high gantries, additional wind-bracing may be necessary between the towers.

In extensive building operations two or more derrick stagings may be required to cover the entire site. In some cases where two derricks are needed and there is not room for two stagings, one square staging is

constructed with four supporting towers, the derricks being placed at two opposite angles.

Scaffold Accidents and Legislation

Precautions against Accidents.—In spite of the greatest care, accidents may always be expected to occur in the conduct of building operations, those of most frequent occurrence arising from the taking of unnecessary risks by workmen, imperfectly constructed scaffolding, and defective appliances for handling materials.

The following notes briefly summarise the chief precautions that should be taken for the prevention of accidents in connexion with the use of scaffolding.

Working Platforms.—Every working platform from which a workman, materials, or tools may fall 8 feet or more should be provided throughout the entire length of the outside and at the ends with a guard rail, 3 feet 6 inches high, having openings for the landing of men and material, and with guard-boards rising at least 7 inches above the working platform.

Bridging Runs.—All bridging runs from which a workman may fall 8 feet or more should be not less than 18 inches wide, and the boards should be fastened together so as to prevent unequal sagging. Where practicable, properly constructed gangways are preferable to ordinary runs.

Scaffold Boards.—All boards forming part of a working platform or run should be carried at each end by a putlog or other support, and should not project more than 6 inches beyond it unless lapped by other boards resting partly on or over the same putlog and partly on other putlogs. Where the boards are butted, the putlogs supporting the ends should be within 12 inches of each other, and the boards should project for an equal distance beyond the putlogs.

Ladders.—Ladders should rise at least 6 feet above the platform to which they give access; they should stand on a level and solid footing, and be securely fixed at the upper point of support. Two ladders should not be spliced together for the purpose of obtaining extra length.

Openings in Working Platforms.—Openings in a working platform through which a workman may fall 8 feet or more should be provided with a guard rail or be fitted with trap-doors.

Removal of Bark from Poles.—All poles should be barked before use, otherwise the lashings will tend to slip, especially if supporting ledgers.

Inspection of Plant.—All scaffolding materials, accessories, and plant should be constantly examined, and anything found to be defective should be so disposed of that it cannot be used for scaffolding purposes.

General.—A working platform should not be used until its construction is complete, unless the uncompleted portion is effectively guarded.

Alteration of or modification in the construction of scaffolding should not be made except by the permission and under the superintendence of some person in authority.

In places where the scaffolding has not been erected by the direct employer of the workmen using it, the employer should see that the

foregoing conditions are complied with before allowing the scaffolding to be used by his workmen.

Slinging Steel and Timber.—In slinging steel girders and columns, and long pieces of timber, a softener or piece of sacking should be wrapped round before the chain is applied; the chain should be turned twice round the softener and knocked as close as possible. This procedure will obviate the slipping which is apt to take place if the chain is applied direct to the material to be hoisted.

Slinging Crates.—Crates without sides, as used for slinging bricks, can be employed safely if tightly packed, as the pull of the sling causes the ends of the crate to grip the material. If the latter is loosely packed, some of it may fall out during the operation of hoisting.

Slinging Baskets.—Ordinary baskets, if slung from the handles only, constitute a source of danger. If used at all, the sling should be passed round the bottom, but it is better to employ one of the various types of basket now obtainable in which wire rope is woven so as to prevent the handles and bottom from breaking away.

Inspection of Hoisting Plant.—The chief precautions to be taken in connexion with cranes and hoisting appliances generally are to see that all moving parts are adequately fenced, that the appliance itself is securely fixed, and that the ropes, chains, and other parts of the hoisting tackle are of ample strength and in good condition. It is particularly important that new chains should be tested before acceptance, and that old chains should be carefully examined and tested from time to time.

Legislation affecting Scaffolds.—The undermentioned Acts and byelaws should be considered by those who are responsible for the construction and use of any temporary structure which is regarded as a scaffold from the legal standpoint:

Factory and Workshop Act of 1901.
Workmen's Compensation Act of 1906.
Notice of Accidents Act of 1906.
Corporation of London: Regulations for Scaffolding.
Burgh Police (Scotland) Act of 1903.

CHAPTER V

CENTRES AND MOULDS

CENTRES

By Alfred W. S. Cross, M.A., F.R.I.B.A.

Definition.—The shaped wooden frames provided for the temporary support, during construction, of arches, vaults, and domes are known as *centres.*

Centres for Arches

Classification.—The structural arrangements of arch centres are almost as varied as the forms and sizes of the permanent structures they temporarily support.

Centres, other than simple *turning-pieces*, *a*, Fig. 41, supported by struts, *bb*, are composed of two or more *ribs*, RRR, Fig. 42, shaped to the contour of the arch and covered at the top by stout battens or *laggings*, *lll*, nailed across them as in Figs. 42 and 43. The ribs are either built up in two thicknesses nailed together and overlapped, as shown in Figs. 42 and 43, or are framed with quartering, 4½ inches by 3 inches and upwards in size, after the manner of a timber roof truss, as in Fig. 45.

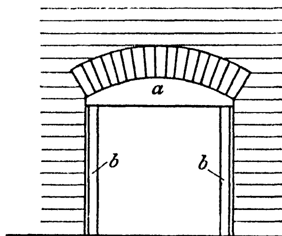


Fig. 41.

Centres with built-up ribs are suitable for spans up to about 20 feet, trussed centres being required for larger spans. Ribs, RRR, Fig. 42, are usually fixed from 2 to 6 feet apart, the intervals being regulated by the weight of the arch and the thickness of the lagging. For rough arches the laggings are generally spaced about an inch apart, but where, as in gauged brickwork, it is necessary to set out the brick courses upon the centre, the boards are fixed close together and the surface worked to a smooth and regular face. The laggings of centres used in the construction of stone arches are sometimes spaced according to the length of the voussoirs and sometimes omitted altogether. In the latter case small settling wedges are placed under each end of the voussoir as it is fixed in position, to bring the block of stone accurately to its bed.

The increasing load on the centre, brought about during the construction of an arch as voussoirs are added on either side, sets up varying stresses in the timber centre. At first the tendency of the pressure from

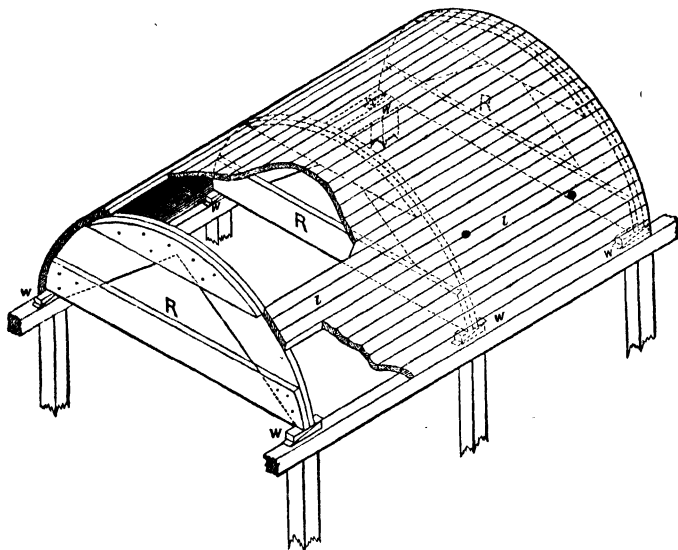


FIG. 42.

the load is to raise the crown of the centre and to depress its haunches, but, at a later stage, when the arch has been completed, the crown of the centre is forced downward and the lower portions tend to bulge outward. To resist these varying stresses, which otherwise would result in the deformation of the curve, *braces*, capable of withstanding both compressive and tensile strains, are introduced. These braces either radiate from the centre of the curve, as in Fig. 43, or, in the case of an elliptical arch, are placed normal to the curve at the point of intersection, see Fig. 44. The lower ends of the braces are either framed into king-posts, or the pressure is taken directly to the ground by a vertical central strut (Fig. 43). The lower horizontal member of a centre that secures the rib at its extremities and prevents it from spreading is called a *tie*.

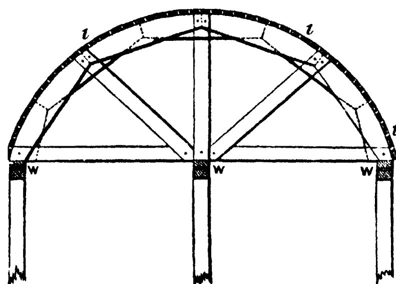


FIG. 43.

Construction of Centres.—To minimise the risk of subsequent distortion while being fixed in position, centres of large size should be carefully

set out, worked, fitted in sections, and afterwards put together as a whole before being refitted and refixed *in situ*.

Scantlings for Centres.—The rigidity of the framework of a timber centre depends to a far greater extent upon the judicious and scientific arrangement of its component parts than upon the size and strength of the latter. For a brick arch 2 feet 3 inches thick and of 20 feet span, the

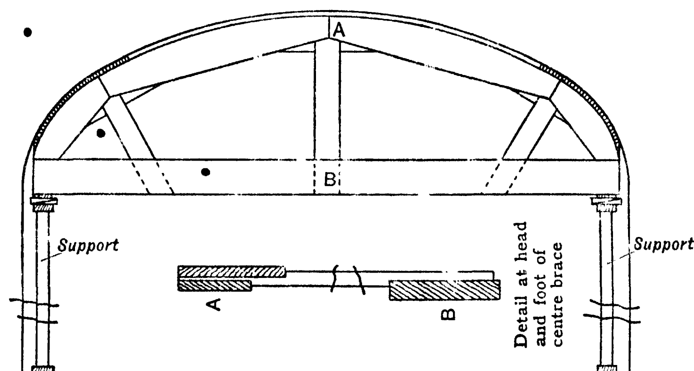


FIG. 44.

centre post, braces, and other portions of the ribs would be cut out of 2-inch fir, the laggings would be $1\frac{1}{2}$ inches thick for ribs placed 3 feet apart, and 2 inches thick for ribs 4 or 5 feet apart.

Fig. 45 illustrates *self-supporting* framed centring, designed to stand without any intermediate support.

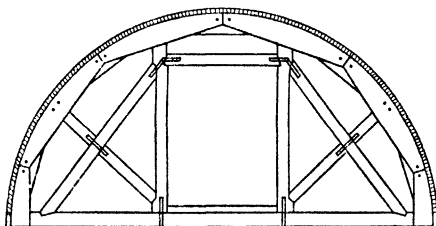


FIG. 45.

Supports for Centres.—Wherever possible, the *supports* or upright timbers (Fig. 43) should be placed at the extremities of the ribs and under the junctions of the braces and tie, and, with a view to the uniform distribution of the load, the lower ends of the supports should rest upon sleepers. Ordinarily, each rib can be supported by upright posts placed at the necessary intervals beneath the tie; but when greater space or height is required for working purposes, trussed ribs of a special kind, designed after the manner of a collar-beam roof, are used.

Easing Centres.—Except in the case of very small structures, arrangements should be made for *easing the centre*, that is, for gradually depriving the arch of its supporting centre, and allowing the weight of the newly formed structure to be slowly transferred to the abutments. For this purpose either lifting jacks or, more frequently, wedges are used. In the latter case pairs of greased wedges, WW, Figs. 42 and 43, are inserted

between the head of the supports and the plate upon which the ribs of the centre rest. After the arch has been turned and its haunches have been filled in, the wedges are driven out, with the result that the centre is lowered, the mortar joints being compressed as the arch settles and takes its bearing on the abutments. Subsequently when the mortar has thoroughly set, the centre is finally removed or *struck*, as it is technically termed.

Steel Centres.—Ribs formed of rolled steel joists, having their top member bent to the required curve and their lower part trussed, are often used for the centring of very large arches. Centres of this description are eased by screw jacks placed at their extremities.

Centres for Skew Arches.—When the acuteness of the angle made by the face of the arch with its piers or abutments, or, in other words, when the *skew* of the arch is inconsiderable, the centring is usually set up in the ordinary way with the ribs placed at right angles to the abutments. In this case the centring necessarily projects beyond the face of the arch. But when the plan of the skew arch forms a very acute angle, the ribs are fixed parallel with the face of the structure to be supported, and consequently their outline is not in conformity with the true section of the arch.

Centres for Concrete Arches.—Laggings used for concrete arched structures should not be more than 3 or 4 inches wide. The boards should be closely laid, the joints being run in with whiting and plaster of Paris. Care should be taken not to disturb the centring until the concrete has become thoroughly set.

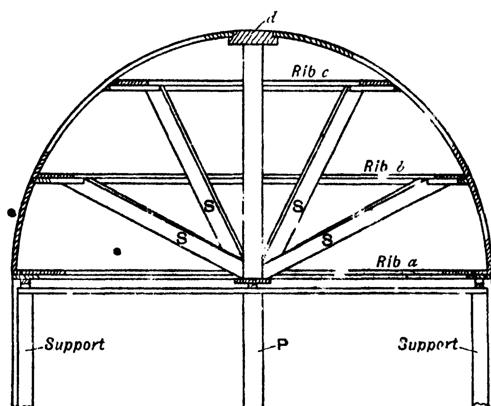
CENTRES FOR VAULTS AND DOMES

Centres for Barrel Vaults.—Centres for *barrel* or continuous vaults are constructed in a manner very similar to those used for ordinary arches. When intersections of smaller span penetrate the main vault the centring for the latter is first formed, and then the ribs for the smaller vault are set up in position, one being placed in contact with the springing point of the main centre, and the others fixed at the requisite distance apart. After the smaller centres have been properly levelled the lagging pieces are placed on them, each of the boards being extended beyond the end rib until it touches the surface of the main centre, to which it is carefully scribed and fitted.

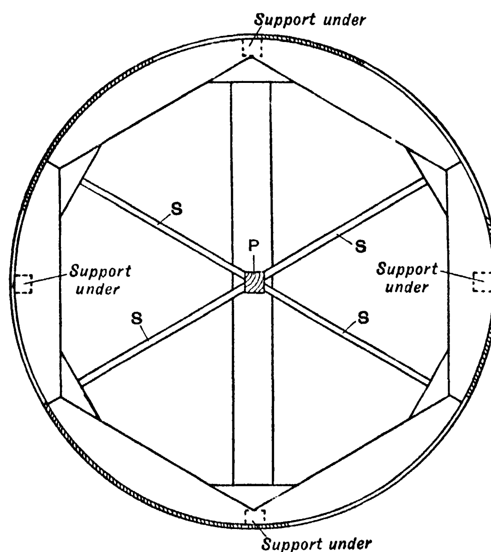
Centres for Groined Vaults.—In centring of this description the various ribs are fixed vertically upon a base frame halved at the angles and secured by nails. The groin ribs are formed in two thicknesses, the shape being obtained by projecting ordinates from points in the curve of the elevation of the intersecting arch to cut the plan of the groin rib, and by erecting perpendiculars from the points thus found equal in length to the corresponding lines in the elevation, as more fully described in Chapter IX.

Centres for Domes and Niches.—Centring for domes consists of a

series of ribs circular on plan, and of varying diameter to suit the contour of the dome, placed horizontally at intervals of about 2 feet between the springing of the dome and its crown, as shown by the vertical section in



Vertical Section

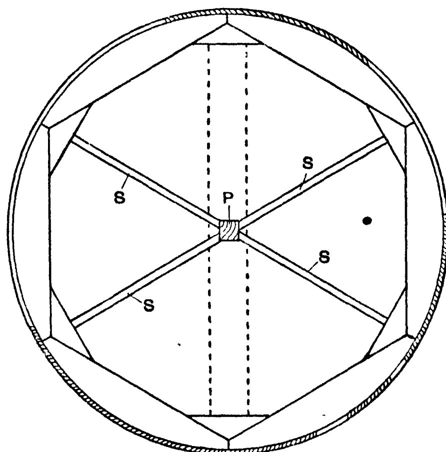


Plan of Rib *a*

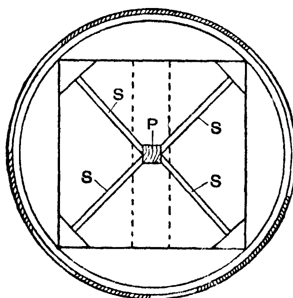
FIG. 46.—Centring for Dome.

Fig. 46. The ribs, the first of which is fixed at the springing line, are supported by struts, S, radiating from a central support, P, terminating at the top in a solid wood disc, *d*, which is rebated to receive the ends of

the lagging, and forms the crown of the centring. Centres for large niches are usually constructed in the manner described for domes (Figs. 46 and 46*a*), the semicircular shafts being built upon horizontal centres formed to the required curve.



Plan of Rib *b*



Plan of Rib *c*

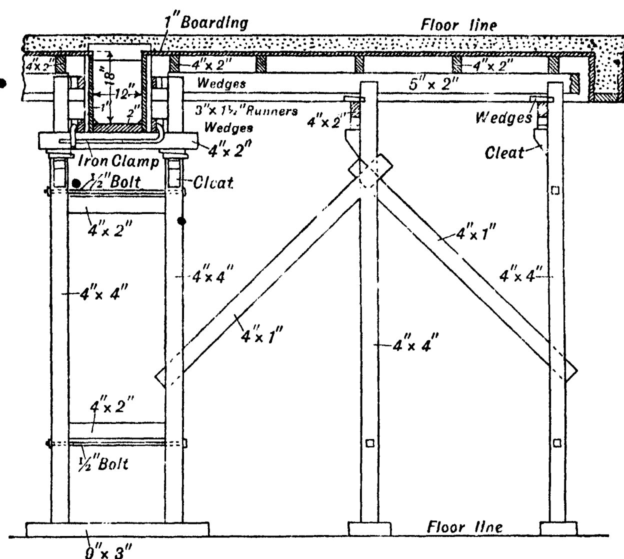
FIG. 46*a*.—Centring for Dome.

MOULDS AND CENTRING FOR CONCRETE

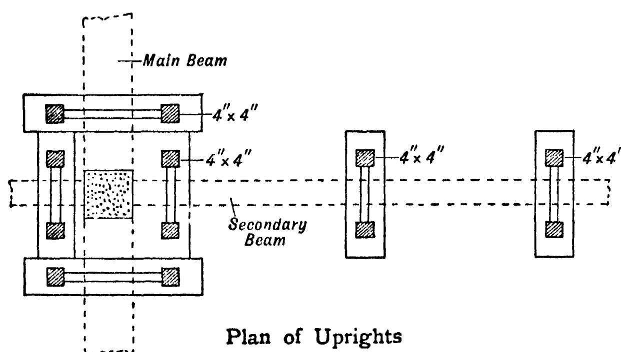
BY W. NOBLE TWELVETREES, M.I.Mech.E., M.Soc.Ing.Civ.

General Construction.—Timber for moulds and centring should neither be too dry nor too green. In one case there may be excessive swelling, and in the other leaky joints may occur, tending to form cavities in the concrete. All moulds and centring should be in proper alignment, rigid enough to carry the semi-fluid concrete without distortion, and must

be adequately supported by struts. They should also be braced laterally, especially in open air work. Considerable saving of timber and labour can be effected by planning all details in accordance with a well-devised scheme, where due regard is given to erection, taking down, and subsequent



Main Beam Mould



Plan of Uprights

FIG. 47.

re-erection elsewhere on the site. Nails should be used sparingly, wedges and clamps being preferable. Where nails are found indispensable, they should not be driven home, but left with the head projecting slightly, so that the nails can be drawn without injuring the timber. In most buildings two or three sets of moulds will enable the contractor to carry out the work economically and satisfactorily, as the timbering first used

can be taken down and re-erected as soon as the concrete has set, while intermediate sections of the work are hardening in the second, or second and third set of moulds.

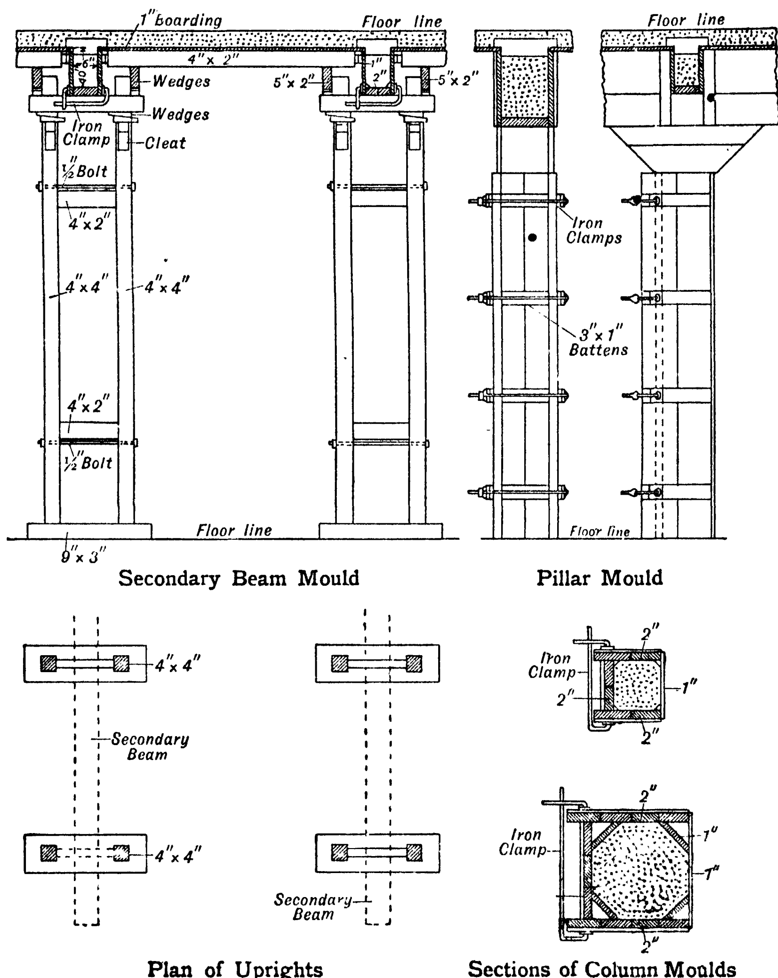


FIG. 48.

Scantlings for Moulds and Centring.—Moulds are constructed of boards and battens of small scantling, the spacing of the latter being governed by the thickness of the boards. For columns the boards are usually 2 inches thick for three sides, the fourth side being formed of 1-inch strips, added as the work of concreting progresses. Beam moulds

should have sides 1 inch to 1½ inches thick, with 2-inch boards for the bottom. Floor centring is generally formed with 1-inch boards. For walls 1½-inch boards are sufficient, but in heavy construction the thickness of 2 inches is desirable. For further details see Figs. 47, 48, and 50, which are taken from *Everyday Uses of Portland Cement* (The Associated Portland Cement Manufacturers, Ltd.).

Column Moulds.—Wherever possible moulds for columns should be built with at least one side open from top to bottom in order that the concrete may be deposited in layers of not more than 9 inches thick, and the opening filled in board by board before each layer is deposited. Column moulds made with all four sides closed, as rendered necessary by some methods of reinforcement, carry the risk that shavings, pieces of timber, and rubbish may be dropped into the moulds and inadvertently incorporated in the concrete. Moreover, when concrete is poured in from the top of a closed mould, the aggregate tends to settle and the cement to rise, thus making the concrete of unequal constitution and strength. Rectangular moulds should be provided with triangular strips, filling up the corners so as to form columns with chamfered corners. Columns connected with beams should be moulded with inclined surfaces on two sides, so as to form a knee-brace connexion below the ends of the beams.

Beam Moulds.—All moulds for beams should be designed and constructed so that the sides can be removed as soon as the concrete has set sufficiently to support its own weight, with the object of permitting the surfaces to be exposed to air. The sides should be clamped at intervals so that they may not be pushed outward by the pressure of the wet concrete. The bottom should have a camber of about 1 inch in 20 feet, and should be supported in order to obviate deflection before the concrete has set. The struts for this purpose should be adjusted and fixed in position by wedges or other suitable means, and placed on timber bearers, where necessary, to prevent them from penetrating into the ground or from causing injury to any finished work below the lower end.

Floor Centring.—The centring for floor slabs should be formed of boards laid between the beam moulds with close joints to prevent the percolation of water from the concrete. Transverse bearers should be provided to prevent sagging, and the whole construction adequately supported by struts as for beam moulds.

Suspended Floor Centring.—If, as sometimes happens, the centring for concrete floor panels between rolled steel beams cannot conveniently be supported by props from the floor below, it may be suspended, as shown in Fig. 49, by means of iron hanger plates and bolts, the plates carrying the ends of temporary wooden bearers, on which the centring is laid, being spaced at regular intervals.

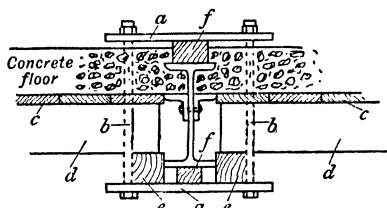


FIG. 49.

a = Hanger plate. *b* = Bolts. *c* = Centring. *d* = Wood bearers. *e* = Plate. *f* = Packing piece.

Wall Moulds.—For moulding wall panels between columns and beams, the requisite shuttering can be built up board by board between posts as the concrete is deposited, or one side of the shuttering can be completed first and the other side built up progressively with the deposition of the concrete in layers. An alternative method is to use movable moulds having clamps permitting them to be secured to the upper part of the wall section last completed, and moved upwards after the concreting of each successive section. Fig. 50 illustrates a convenient type of movable mould for wall construction.

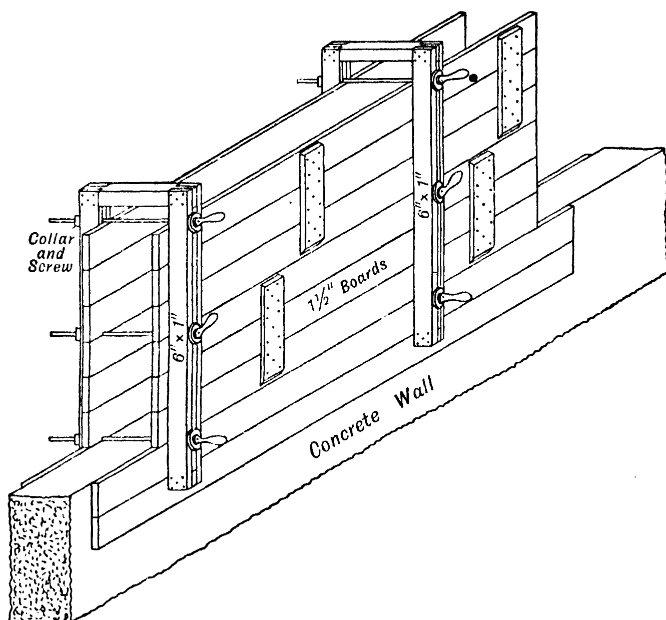


FIG. 50.—Movable Wall Mould.

Preparing Moulds for Concreting.—If the moulds are not used shortly after erection, the joints should be examined and made good where shrinkage has occurred, and the supports and bracing tightened up as necessary. In warm weather the inside of the moulds should be wetted to prevent the absorption of water from the concrete. As concrete adheres to boards which are removed before the material has thoroughly set, it is generally advisable to treat the interior of moulds with limewash, soft soap, or oil before the deposition of concrete. Before any concrete is placed in the moulds, the latter should be carefully examined and any rubbish removed.

Removing Moulds and Centring.—The removal of moulds and centring should always be performed by trained men. Care should be taken to avoid causing shock and vibration, and injury to the surfaces and edges

of the work. Care should also be taken to avoid injuring the timber so as to unfit it for use again on the same and other contracts. No moulds, centring, or supports should be removed without direct instructions from some authorised person. This is important, as the premature removal of moulds and supports has been responsible for most of the failures which have occurred in reinforced concrete construction.

Column Moulds.—The sides of column moulds may be removed after about seven days, thus exposing the concrete on all sides and hastening the process of setting. It is important that adequate provision shall be made for relieving the new concrete from all load until the work has thoroughly hardened.

Beam Moulds.—As soon as the concrete has set hard enough to hold together and carry its own weight, the side boards of beam moulds can be removed, but the bottom boards and struts must be left in position for about three weeks, or longer if found necessary.

Slab Centring.—The time during which the centring should remain after the completion of concreting depends very much upon the length and width of the slabs, and upon the state of the weather. If the centring is constructed so as to permit removal of the boards before interfering with the struts and bearers, the boards may generally be taken away after about ten days, the supports being left in place for a further period of about fourteen days.

Wall Moulds.—The shuttering for wall panels can generally be removed after the lapse of from four to seven days in summer, and about ten days in winter, unless setting of the concrete has been delayed by unfavourable weather or other causes.

CHAPTER VI

BRICKWORK

BY PROFESSOR BERESFORD PITE, F.R.I.B.A.

GENERAL

Materials.—The materials of brickwork, described in detail in Part III., are: (1) Bricks of regulation size, square, *i.e.*, rectangular unless of special shape, hard and sound of texture; where required for external surfaces of good colour, even or varied, or glazed for the purpose of reflecting light in areas and opposite windows; (2) mortar or cement properly compounded of good materials in correct proportions and supplied in ample quantity.

Standard Size of Bricks.—Fig. 51 illustrates the standard size of bricks

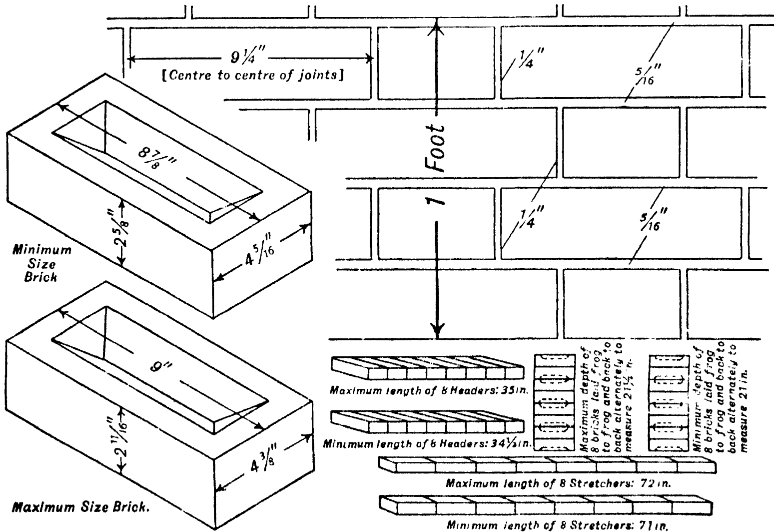


FIG. 51.—Method of measuring Standard Sizes of Bricks.

and method of measurement for brickwork agreed upon between the Royal Institute of British Architects and the Brickmakers' Association.

TECHNICAL TERMS

Frog.—Upon the top surface of a brick there is an indent, formed in moulding the clay, which is called the *frog*. The formation of the frog hardens the core by pressure in moulding upon the body of the brick, and also, by counteracting any tendency to swell, secures the horizontal line of the edges of the brick. The frog is laid uppermost, and when filled up with mortar forms a joint which keys or locks the brick into the wall.

The fine quality brick made to rub, or cut for arches or moulded work, is without a frog, as the indent on the top side may not be required, and is likely to be inconvenient when the brick is being reduced to a special shape.

Wirecuts.—A wirecut brick, mad by cutting with wires a band of clay pressed through a machine, has no frog.

Approximate Size.—The size of a whole brick is a little less each way than 9 inches long, 4½ inches broad, and 3 inches high. These dimensions, though inexact, are sufficient for general use; they may be taken as including with the brick its average share of the surrounding mortar.

Brickwork.—The following are definitions of terms in regular use in connexion with brickwork:

Stretcher.—A whole brick laid with its length parallel with the face of a wall is a *stretcher*.

Header.—A whole brick laid with its length across or at right angles with the face of the wall is a *header*.

Laid Dry.—Bricks laid without any mortar are said to be *laid dry*.

Splay End.—The opposite end of a brick to that which is laid squarely by rule is said to be the *splay end*.

Course.—One horizontal layer of bricks throughout the length and breadth of a wall is a *course*. The courses of brickwork in an entire building composed of many walls and piers should preserve an exact series of level lines. *Stretching and heading courses* contain respectively only stretchers or headers; these terms only apply to external or visible courses.

Bed.—The horizontal surface upon which a course of bricks is laid in mortar is the *bed*.

Cross Joints.—The vertical mortar joints which enclose the back and sides of the brick in position in the wall are the *cross joints*. The exposed edges of these vertical joints should alternate in strictly perpendicular lines, according to the system of bond or overlapping employed.

Transverse Joints.—A joint which crosses the bed in a continuous line is a *transverse joint*. If a transverse joint should occur immediately over a portion of another transverse joint a serious defect is occasioned in the bond which is called *straight joint*; this defect is of course as dangerous if it occurs inside a thick wall as if it reveals its presence in the pointing of the surface. Settlement or failure of the wall follows upon this defective construction.

Closers.—In arranging overlapping courses to create bond and to form vertical ends or openings, it is necessary to use a quarter or a three-quarter brick. These reduced bricks are termed ***closers***, because they

close up the bond next to the end brick of the course. The quarter brick, which is 2¼ inches wide, is a closer, and is usually only half a brick in depth.

Queen Closer.—A *queen closer* is 2¼ inches wide but a whole brick in depth. As bricks, however, cut more easily into quarters without waste, the use of two quarter brick closers is more usual.

King Closer.—A three-quarter brick, used to preserve the bond of the surface, is a *king closer.* It is usual to cut only the angle diagonally off the king closer, as it is not easy to cut an internal angle in a brick; this necessitates also cutting the adjoining brick in the face course to fit the king closer. The use of king closers in the internal angles of walls instead of smaller pieces is to be preferred.

Bats.—Bits of brick are called *bats.* Except where used as proper closers to a course, the use of bats should be prohibited. If in the setting out of brickwork the factors of dimension correspond with the bricks which are the factors in the wall, the use of bats can be avoided.

Bond.—In brickwork, *bond* is the term used to describe the principle or method on which the bricks are laid in horizontal overlapping courses to form perpendicular walls of various thicknesses. The practical and essential object of bonding is to prevent the vertical joints in any course from falling directly over those in the course above or below by securing an arrangement which ensures a proper overlapping of each vertical line. The various systems of bonding are described and illustrated in the succeeding section of this chapter.

Wall Dimensions.—In describing brick walls it is proper to use terms of bricks thus :

Half-brick Wall.—A half-brick wall is built wholly of *stretchers,* and is a half brick or 4½ inches thick.

Whole-brick Wall.—A whole-brick wall is 9 inches thick, which is the length of one whole brick.

Brick-and-a-half Wall.—A brick-and-a-half wall is a little more than 13½ inches thick, as a mortar joint has to be added in. This wall is usually called 14-inch.

Two-brick Wall.—A two-brick wall is two whole bricks laid transversely in thickness, that is, 18 inches thick.

Two-and-a-half-brick Wall.—Similarly, two-and-a-half-brick walls are about 1 foot 11 inches thick, three-brick walls 2 feet 3 inches thick, and so on.

BOND

Brickwork is the art of bonding bricks together into a building. There are several systems of bonding, as described below, but in each the separate relation and action of the bricks have to be considered apart from the adhesiveness imparted by the mortar used in the joints.

Straight Joint.—When work is properly executed each brick *breaks joint* vertically with all its neighbours, failure to do so produces *straight joint,* that is, a continuity of vertical joints. The prevention of *straight joint* is the end to be attained by bonding.

Straight joint is an evil to be prevented not only upon the faces of a

wall, where it would be self-evident, but within the thickness of the wall, where also its presence might cause fatal disintegration.

Transverse Joint.—A guiding principle in setting out the bond of a wall is that in each horizontal course the transverse joints, from the front to the back surface on plan, should be continuous. If this is consistently maintained the vertical overlapping of the joints in elevation will obviate straight vertical joints in the middle of the wall. Reference to the diagrams of various systems of bond (Figs. 52 to 68) will illustrate this point.

The principle of continuous transverse joints means that the bricks do not *break joint* on plan as they do in elevation. It is not necessary that they should do so, and any attempt to break the joints on plan will involve some internal straight joint. The mischief of dividing up the interior of a wall into vertical sections need not be enlarged upon; it is simply destructive of load-bearing capacity.

Vertical Joints.—It has been urged that unless all the vertical joints are carefully filled up, which is not always done in practice, it should be advantageous to break the transverse joint, but the result would not counterbalance the loss of stability. The vertical joints must be properly filled up. Only ordinary care is required to secure this and to maintain the rule of continuous horizontal joints, an easily applied rule for providing sound bond.

VARIETIES OF BOND

Heading Bond.—In heading bond (Fig. 52) every brick is laid as a header, each 4½-inch face breaking joint above and below. A bond of this character has not the power, which stretchers impart, of resisting or transmitting pressure in the direction of the length of the wall, and consequently is not employed for walling.

Use.—It is used for footings (as in Fig. 52) where stretchers, if used for the diminishing courses, would receive the weight of the superimposed course in the middle of the frog, and not afford so good a bond into the substance of the wall.

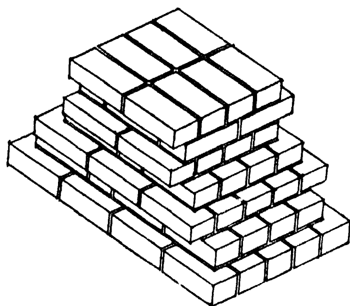


Fig. 52.—Heading Bond in Footings.

Heading bond is useful in such exceptional cases as walls which are convex or concave on plan, where the curve can be achieved by thinning the radiating cross joints or by slightly reducing the size of one end of the bricks.

The same bond is also necessary for the construction of corbellings in brickwork, where a projection is required in each course.

In panels of gauged rubber brick for carving, headers only should be used in order to reduce the risk of cutting into the heart of the facework.

Stretching Bond.—In stretching bond (Fig. 53) all the bricks are stretchers, each vertical joint falling upon the centre of the stretcher above and below, no angle closers being required.

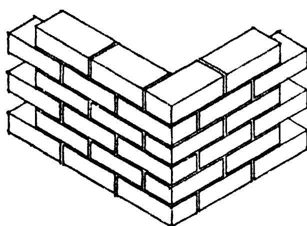


FIG. 53.—Stretching Bond.

Use.—This bond is largely used for internal partition walls of 4½-inch thickness, and for the lining or facing of hollow walls for resisting dampness, in which latter case ties are employed to bind the half-brick wall to the main thickness across the internal hollow space. Stretching bond should not be used for walls of greater thickness than half brick, as it creates no internal bond; the strength of two parallel half-brick walls built close against one another is much less than that of a bonded wall one brick thick.

This bond is generally used for the internal division walls of domestic chimney-stacks as well as for the outer walls, which, however, should be built of 9-inch work if possible. Stretching bond is sometimes described as *chimney* bond.

English Bond.—This is the simplest combination of whole bricks, each course being alternately wholly composed of stretchers or headers (Figs. 54 to 57). It does not involve the use of any bats within the wall, and in this respect gives a better result than any other form of bond.

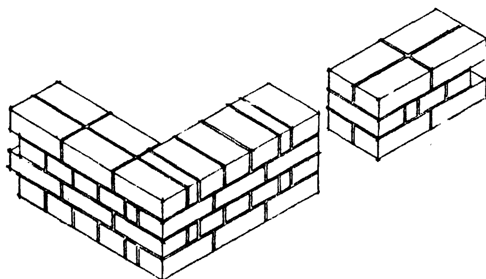


FIG. 54.—English Bond (one brick).

Use.—English bond is not desirable in walls of one brick thickness (see Fig. 54), as there is no opportunity of compensating by the joint within the wall for the slightly differing length of the header course and that of the two stretchers with a joint between them, which compose the alternate courses. The result is an uneven surface, but for all walls of greater thickness than one brick it is the best bond.

Brick-and-a-half.—In a wall one brick-and-a-half thick the headers and a row of stretchers make up each course, the stretchers showing alternately on the inner and outer faces of the wall (see Fig. 55).

Two Bricks.—In a wall two bricks thick (see Fig. 56) the heading courses are composed of two rows of headers and the stretching courses consist of a row of stretchers, both on the inner and outer face filled in between with headers laid transversely. It must be noted that the treatment of the heading and stretching courses varies, as the stretching courses are not composed of stretchers throughout the thickness of the wall. If it were so a straight joint would be created at the back of the headers from top to bottom of the wall.

Two-and-a-half Bricks.—In a wall two-and-a-half bricks thick (see Fig. 57), and in all walls containing an odd half brick in thickness, the principle applies as described for a one-and-a-half brick wall, namely,

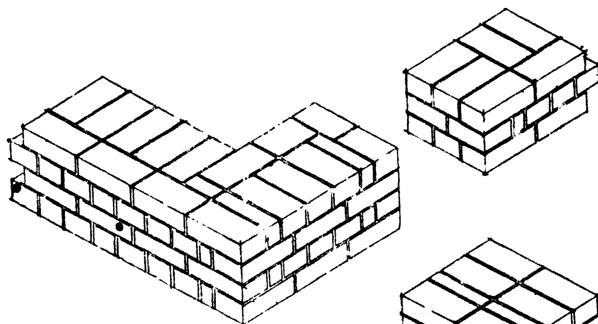


FIG. 55. English Bond (brick-and-a-half).

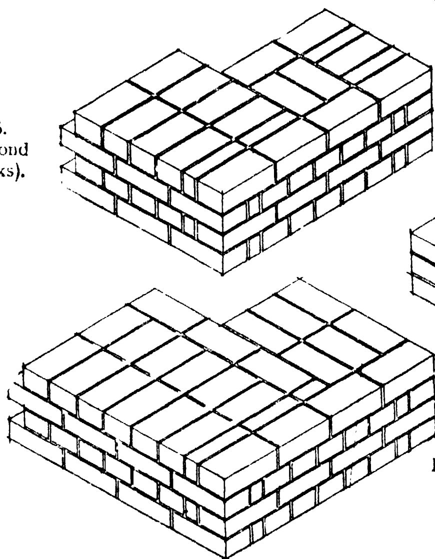


FIG. 56. English Bond (two bricks).

FIG. 57.—English Bond (two-and-a-half bricks).

that the courses which show stretchers on the outer face show stretchers on the inner, and *vice versa.*

Greater Thicknesses.—In all walls of a thickness of whole bricks, every course will be headers or stretchers on both faces of the wall, the transverse filling being always of headers Care must be taken in adjusting the thickness of the joints to prevent the space occupied by the headers from outrunning that taken up by the stretchers, two headers and three vertical joints being kept equal in length to one stretcher and two vertical joints.

Dutch Bond.—A modification of English bond which strengthens

the angle is called *Dutch* bond (Fig. 58). Instead of terminating the heading courses with a quarter closer next to the quoin header, a three-quarter closer is used to terminate each course of stretchers, and the stretching courses are themselves alternated by the insertion of a header next to the angle closer in every other course. The result is that the vertical joints of one stretching course fall upon the centre of the stretchers in the next recurring stretching course.

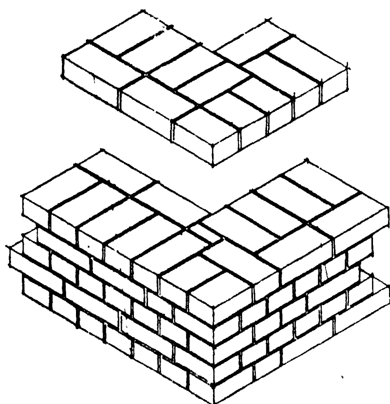


FIG. 58.—Dutch Bond.

Flemish Bond.—In *Flemish* bond every course consists of both headers and stretchers. A header is placed in the centre of the stretcher of the course both above and below it, so far like English bond, but unlike it in that each header is separated from the next in the course by a stretcher. The distribution of headers and stretchers assists to conceal the difference in thickness of a header and a pair of stretchers. Flemish bond maintains the vertical relation between the alternating headers more easily than English bond, where the headers and stretchers are in separate courses.

The drawback to this bond is the necessity of the use of bats in the wall.

Double Flemish Bond.—When used upon both faces of the wall this bond is called *Double Flemish* (Figs. 59 to 62).

One Brick.—Flemish bond produces walls of whole bricks only, when used for those of one brick thickness (Fig. 59). Wherever an odd half brick occurs in the thickness the presence of a half-brick bat is required by this bond.

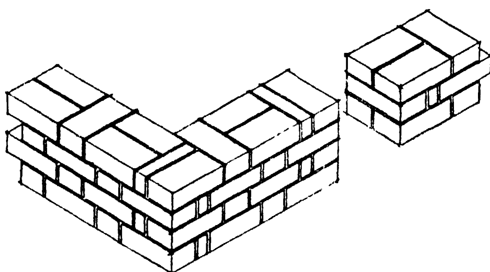


FIG. 59.—Flemish Bond (one brick).

One-and-a-half Brick.—In the wall of one-and-a-half brick thickness (Fig. 60) it occurs in the middle, and in other walls of an odd half brick on the alternate courses of both faces of the wall.

Single Flemish Bond.—This is a combination with English bond for the body of the wall, and Flemish for the facework only (Figs. 63 to 65). This combination is the most general, as it provides Flemish bond with the advantages of English bond for walls of a varying thickness, the walls of every building being composed of stories of diminishing thickness from the foundation to the top.

Facing.—The use of a special quality of facing brick usually justifies the method, but lends itself too often to the use of half headers, in order to economise the facing bricks. This increase of the number of bats is bad, but it is to be feared that the conscience of the modern bricklayer is hardened as to this error.

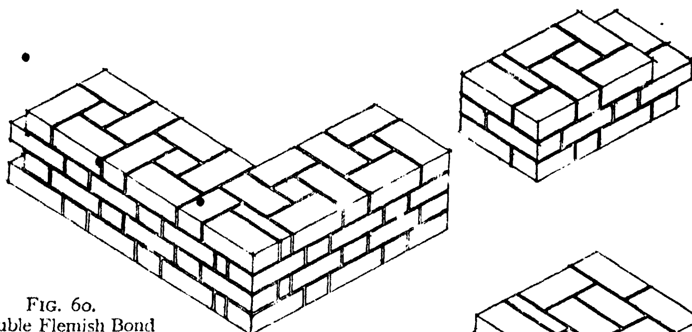
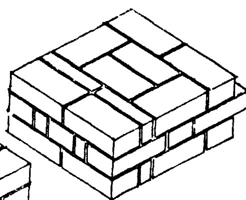


FIG. 60.
Double Flemish Bond
(brick-and-a-half).



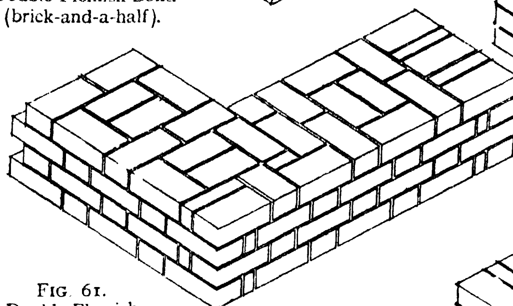


FIG. 61.
Double Flemish
(two bricks).

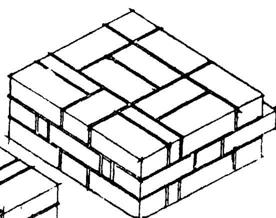


FIG. 62.—Double Flemish
(two-and-a-half bricks).

False Headers.—Unless the use of false headers in the facings is carefully diminished in walls having an odd half brick in thickness, with half headers on the inside or in the middle of the wall, a vertical joint will be made which will separate the facework of Flemish bond from the body, which is of English bond. A distribution of the unavoidable vertical joints is all that can be effected.

Whole Brick Walls.—In walls of whole bricks in thickness the alternate courses of facings must be whole headers.

Garden Wall Bonds.—These bonds are useful for low boundary walls of one brick thickness when the only weight to be carried is that of about 7 feet of a wall.

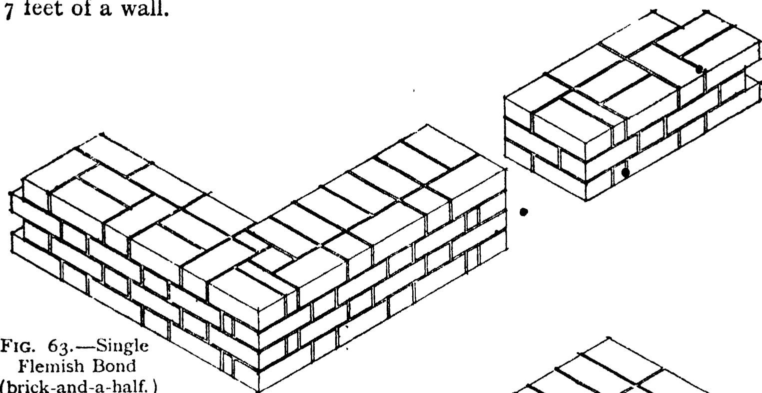


FIG. 63.—Single Flemish Bond (brick-and-a-half.)

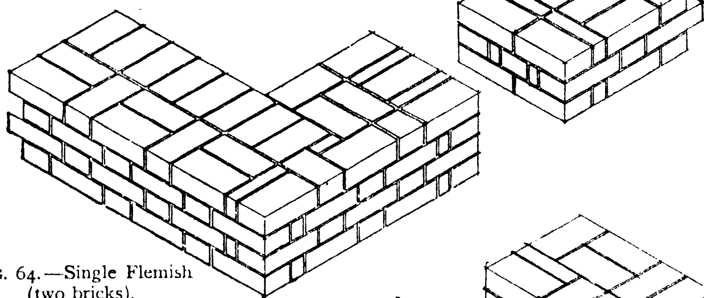


FIG. 64.—Single Flemish (two bricks).

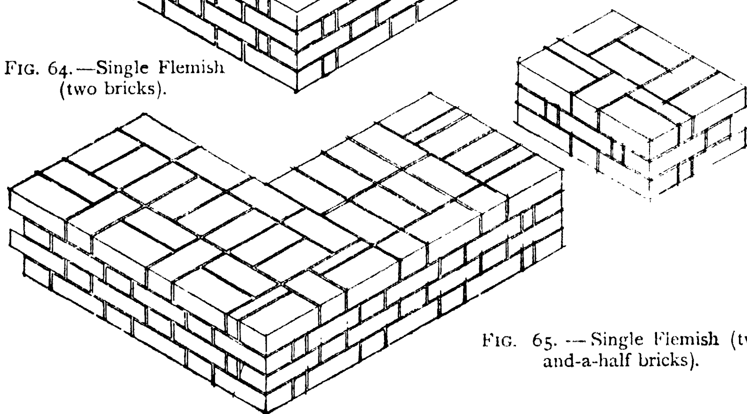


FIG. 65.—Single Flemish (two-and-a-half bricks).

Garden wall bonds are employed to provide a fair face on both sides of a one-brick wall composed of headers and stretchers, owing to the different thicknesses caused by the joint between the stretchers.

Sussex Garden Wall Bond.—This is a variety in which one header and three stretchers are laid in each course throughout.

English Garden Wall Bond.—This variety consists of one course of headers to three courses of stretchers, the headers providing through bond (see Fig. 66).

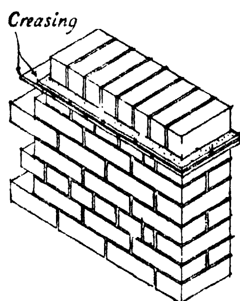


FIG. 66. — Garden Wall Bond with brick-on-edge coping and tile creasing.

Raking or Diagonal Bond.—A form of bond used in walls of exceptional thickness only, with the purpose of radically distributing the vertical pressure through the joints. The courses travel diagonally across the interior of the wall (see Fig. 67), the usual square facework being added and made up with triangular bats. The courses of raking bricks cross one another.

This bond is useful in the courses of footings to high walls. When used as a strengthening bond in thick walls the raking courses are used in pairs at regular intervals in the height of the wall.

Herring-bone Bond.—This is an arrangement of raking bond in both directions from a centre line in the middle of the wall; it has the advantage of making effective bond in the middle. The bond

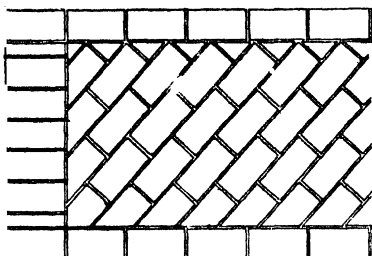


FIG. 67.—Raking Bond.

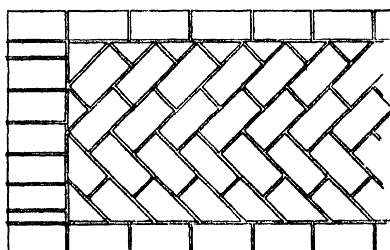


FIG. 68.—Herring-bone Bond.

corresponds with the herring-bone patterns employed for brick pavings (see Fig. 68).

STRUCTURAL DETAILS

Footings.—A foundation being defined as the formation, whether natural or artificial, upon which a building rests, the portion of the wall which immediately stands upon the foundation is built to form a *footing*.

Definition.—Footings in brickwork are courses projecting gradually on both sides until the wall is doubled in width.

Projection.—Every course is increased a half brick in width, projecting one-quarter brick, that is, 2¼ inches on each side. Thus, a wall one brick thick is increased in its lowest footing to two bricks by two projecting courses; a wall one-and-a-half bricks thick to a lowest footing of three bricks, and so on for all thicknesses of walling. The spread of brickwork footings is maintained at a uniform angle on each side by the proportion of the projection of 2¼ inches to the height of the 3-inch course. Thus, in

a one-brick wall 9 inches thick two courses make the width of the bottom footing 18 inches, the total projection on each side being 4½ inches, and the height 6 inches. Similarly, in the one-and-a-half brick wall three courses make the width of the bottom footing three bricks, the total projection 6¾ inches, and the height 9 inches. The rule is thus created that the height from the bottom of the footings is at least equal to two-thirds of the thickness of the wall at its base, that is, at the course above the footings.

Heading Courses.—All the projecting courses of footings are built of headers, that is, in *heading bond* (see Fig. 52), so that the smallest proportionate amount of any one brick projects. Any half bricks that may be required by the bond are kept in the middle of the courses. If stretchers were employed, as in English or Flemish bond, the line of projection of some bricks would lie in the middle of the frog, and they would be imperfectly bonded into the mass.

Double Course.—Sometimes the first or lowest course of footings is laid double, the underneath course being then laid in stretchers without projection. This double course is not necessary where an artificial foundation of concrete is formed, which gives a thoroughly good start to the footings.

Plinths.—It is inadvisable to make a plinth by adding a set-off of a quarter-brick thickness on the outside of the wall only, as bad bond throughout the whole of the wall below the plinth will result. The set-off at the ground-floor level affords a base or plinth. A similar set-off should be provided on the inside face to make out the extra half-brick thickness in which the bond will be preserved.

Corbellings.—Projecting courses of bricks, constituting corbels, are formed to carry constructed features, such as chimney breasts or piers, or for supporting the ends of floors. The total projection should be gradually attained by sailing-over each course for 1⅛ inches to 1½ inches per course. If thus distributed the weight will not snap the bricks which, though individually hard, are brittle. Such corbelled courses are built in heading bond. The beds of all overhanging or corbelled courses maintain the true horizontal line. The weight is transmitted through the mass, and not by means of the joints, as in an arch or retaining wall.

Openings.—Doorways, windows, and other openings in brickwork necessarily break the bond which has to join up properly above and below the opening. This may necessitate a central closer in each course where the bond breaks.

Rebates.—Door or window frames are fitted in shallow recesses called rebates, formed with small projections in the jambs of external walls. The rebate usually increases the width of the opening by a quarter or half brick on each side, and is formed with king-closers (see KK, Fig. 69).

Frames are built into openings in internal walls without rebates, but in external walls the rebate assists in the fitting and fixing of a wooden frame and in excluding the weather.

Reveals.—The reveal is strictly the depth of wall revealed in the sides of the opening beyond the frame. This depth is usually half a

brick, but it may be of any brick dimension. Sometimes the frame is fixed to make the reveal appear less than 4½ inches, or the reveal may be partially hidden by a wooden cover moulding.

Splayed Jambs.—The internal jambs or sides of an opening are often splayed instead of built at a right angle behind the recess in which the frame is fitted, in order to increase the width or improve the light (see Fig. 70). The splayed face can usually be formed by cutting across the bond, replacing any small bats that are created with king-closers. In thick walls the splay would be built up of whole bricks as facework, using squint bricks at the angle, and the bricks in the body of the wall cut to fit the back of the splay. If the jamb is not plastered, but is covered with a wooden lining, the splay may be formed with square offsets.

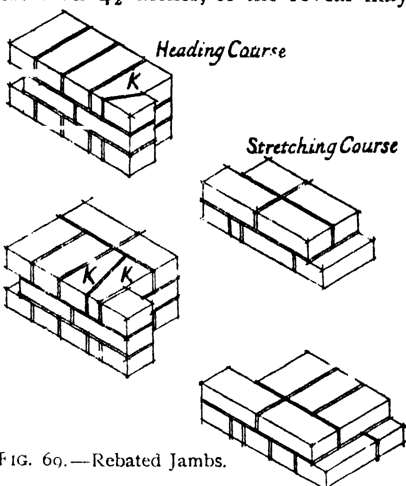


FIG. 69.—Rebated Jambs.

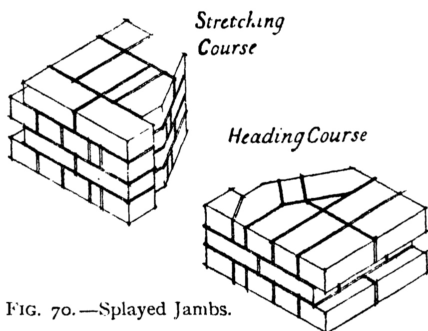


FIG. 70.—Splayed Jambs.

Copings.—Although it is advisable and usual to finish the tops of walls, which are not covered by roofs, with long thin slabs of hard stone, in order to expose only a few joints to the weather, good copings can be constructed of hard impermeable brick.

Brick-on-Edge.—A brick coping is built on edge in cement in courses 4½ inches instead of 3 inches high, thus concealing the frog.

Tile Creasing.—To prevent the percolation of water into the wall below the brick-on-edge coping, a course is formed of two or three thicknesses of plain roofing tiles, set in mortar and breaking joint, as shown in Fig. 66. This tile course or *creasing* projects about 2 inches over each side of the wall, and the upper surface is sloped or weathered from the wall in cement.

Coping Bricks.—Fig. 71 shows some of the shapes of coping bricks commonly used with creasing. It is better, however, to employ a purpose-made coping brick of greater width than the wall, sloped or curved on the upper surfaces, and having a drip under the lower edges to throw off the water (see Fig. 72).

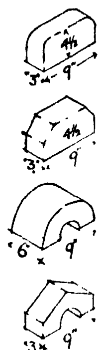


FIG. 71. Coping Bricks.

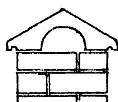


FIG. 72. Coping Brick with Drips.

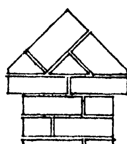


FIG. 73. Ridged Coping.

Ridged Copings.—Peaked or ridged copings are sometimes built of ordinary hard bricks, which offer no horizontal surface to the rain. Upon a plain projecting course, bricks are built at an angle of 45 degrees, the ends of the headers alternating at the ridge, as in Fig. 73. This coping will last if constantly repointed, but it offers more mortar-joint to the weather than any other. Its construction involves cutting the foot of the bricks and bats to a splay.

Slopes.—A wall that has an inclined retreating face is said to *batter.* Batter combined with the vertical is formed by building the bed joints at right angles to the inclined line, and *tumbling-in* wedged-shaped groups which combine with the horizontal bond of the wall.

Pediments and Gables.—The sides of pediments and the copings of gables are formed in brickwork of continuous raking courses, the walling being cut to the required angle on the under side. The raking courses must be properly stopped with blocks at the junction with the horizontal work, and have an apex or key block which avoids a central vertical joint. For these junctions specially cast or moulded bricks are required.

Setting Out Brickwork.—Although it is unlikely that an architect would work out a plan using half bricks as dimensions instead of feet or inches, the bricklayer has to build in brick sizes. Owing to forgetfulness of this initial factor, or to careless setting out, the face brickwork of a wall with many openings is not infrequently spoilt. Good brickwork can be obtained if the horizontal dimensions are all multiples of half a brick, *i.e.* 4½ inches.

Setting Out Rods.—The work should be set out by marking all the horizontal dimensions of the plan with bricks, or in brick sizes upon a deal batten or rod.

Vertical rods are similarly required for heights, the factor being 3 inches. The rods show not only the external heights but the levels of girders, floor plates, and corbels, which it is essential should coincide with the true courses of the brickwork. If packing up is necessary, and appearance is not in question, it is better to employ courses of flat tiles than to cut up a horizontal course of bricks.

Any important feature, such as a rusticated quoin or cornice projection, should be specially set out on a rod, and a wooden mould or template provided as a guide to the bricklayer.

Closer.—Beginning with the first course, laid upon the damp course, a closer will always be set next to the header at the quoin, and the bond will be set out for the ends or angles of each wall. Any odd dimension is arranged by a closer at a central meeting-point, where the bond is said to be broken.

Openings.—The occurrence of window or door openings at regular or irregular intervals will necessitate a new adjustment of the bond from each angle of the subdivision with a proper closer in the centre of each portion. The closer will appear in each course, alternating with the bond. Above the openings where the brickwork is again in continuous courses, the original setting will re-occur.

Sills in Courses.—In elevations, the level of the under side or bed of a window or door sill should coincide with a course of the brickwork. Any closers required to adjust the depth of a sill to the courses should be provided in the jambs above and not below the sill, where the whole bed would have to be cut or packed up.

Springings.—The splayed end of the courses, or skew-back, from which an arch springs should commence exactly upon the bed of one course. It will extend across three or more courses, and any overlapping which does not coincide with a course should be formed at the top and not at the bottom of the skew-back.

Mortar Joints.—The ingredients and mixing of mortar and cement are dealt with under Materials in Part III. Good mortar is essential as well as good bricks, and the proper use of both materials in combination is good brickwork.

Laying.—Laying bricks in mortar, though a simple operation in ordinary circumstances, requires thoroughness. The carelessness and parsimony which leave empty spaces and unfilled joints should be rigorously avoided, though lamentably common.

Filling up Joints.—A joint is not properly formed between attached bricks unless all the surfaces of the bricks, except those exposed, are fully surrounded with mortar. A dab of mortar may stick a brick to its neighbour inside, and it may be pointed up outside, but this is a mere travesty of bricklaying.

Bed Joints.—The horizontal bed must be fully laid, making up all hollows, the vertical joints filled up from below by laying the brick into mortar, and by working down a liberal supply from above. The consistency of the mortar must be adapted to do this properly, perhaps slightly thinned with water to ensure penetration into the interior joints.

Larrying.—In thick masses of brickwork, when a mass of mortar is poured upon the wall and worked in, the process is called *larrying up*.

Grouting.—The use of a very thin mortar which soaks in rather than solidifies in a mass is termed *grouting*. Although useful in some kinds of stonework, this is not desirable in brickwork, as mortar joints are much stronger.

Wetting.—Bricks should be used wet to ensure proper adhesion to the mortar. In the summer a dry and heated brick will evaporate out of the mortar the water necessary for induration.

Frost.—The large amount of liquid necessary in walling makes bricklaying in frosty weather dangerous, and the thermometer is a very necessary guide. Freezing destroys the mortar by preventing setting, and the expansion it sets up bursts off the pointing, and may pull a wall out of shape, but cement mortar, which will set in frost, may be used.

Pointing.—When properly built, the life of external brickwork depends upon the resistance that it is capable of offering to the weather. In the protected portions of a building practically nothing occurs to the brickwork that may be called decay, but rain and frost cause the exposed mortar joints to perish.

Pointing is the treatment of the exposed jointing of brickwork to secure it as far as possible against the action of the weather. Pointing is important as affecting the appearance of the work. It represents the accuracy of the bond upon the surface as well as the neatness of the workmanship of the joint.

Good Bricks Necessary.—Good pointing cannot be obtained with bricks the edges of which are not exactly square and true, or which have been carelessly chipped in handling.

Effect of Weather.—The pointing of brickwork is gradually destroyed by the action of wet and frosts, and therefore has to be replaced from time to time. Good pointing in cement, whether employed in the first instance or in after repair, will preserve a brick wall for many years without re-pointing.

Pointing in Cement.—Cement mortar, which is harder than lime mortar, and offers more resistance to the weather, should be used for pointing chimney-stacks, copings, and all work in exposed positions, even where it cannot be afforded for the whole face of the work. It is true economy to minimise the recurring heavy cost of repointing.

Pointing as Work Proceeds.—The primary or natural method is to complete the jointing of a wall in the process of erection by neatly compressing and finishing the front of each mortar joint with the trowel. The only recommendation of pointing as work proceeds is cheapness. It must be remembered, however, that the scaffolds have to be supported by putlogs until the wall has reached its full height, and the holes have to be filled in when the scaffolding is *struck*. The fixing of rain-water and soil pipes upon the face often entails cutting into the brickwork and making good, and, as mortar droppings have also to be cleaned off, the total work involved is nearly that of completely pointing down the last thing.

Coloured Pointing.—For this a different mortar of special colour, made white with extra *putty* or black with ashes, or pink with red brick dust, may be used according to fancy, or cement mortar may be employed to secure more durable work.

Raking Out.—If the wall is to be pointed, the mortar in the wall is kept back from the front during building about ¾ inch from the face, or raked out to that extent to provide room for the pointing.

Kinds of Pointing.—The several methods of pointing brickwork are: *weathered* or *struck-joint*, *recessed*, *flat*, *keyed*, and *tuck pointing*. These are all applicable to new walling in stock brickwork, although tuck pointing is seldom used for any other purpose than that of giving the best possible appearance to old or defective brickwork.

Weathered or Struck-joint Pointing.—Weathered or struck-joint is the simplest and most common method of pointing (Fig. 74). It is designed to throw the rain off the horizontal joints by sloping the mortar

back about ½ inch. This may be done in two ways, shown in the accompanying sections, by sloping the mortar inwards from the lower edge of the upper brick of the joint (see A), or by sloping from the upper edge of the lower brick (see B). The former (A) protects the mortar from the weather better, but leaves exposed a narrow edge of brickwork on which water may rest. The latter (B) avoids this, as it covers the lower and exposes the upper brick only on its under side, but offers the mortar at an angle to the rain. It is probable that the exposed brickwork will suffer less than the mortar if it is of decent quality. Bricklayers prefer the latter method, which strikes the slope off the upper edge, because the level is applied to that edge in bricklaying. Consequently there is less likelihood of irregularity. In appearance, the slope from the lower edge offers a softer line of shadow than that presented by the slope from the upper edge; this may or may not be preferred.

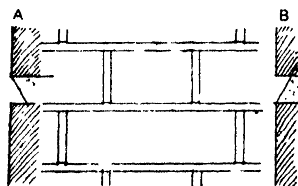
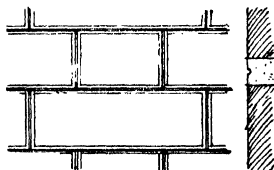


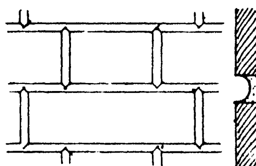
FIG. 74.—Weathered or Struck-joint Pointing.

Recessed Pointing.—A method of pointing, often employed on the Continent but seldom at home, recesses all the joints, vertical as well as horizontal, behind the plane of the wall, with a vertical instead of a splayed surface. Recessed pointing prevents any peeling off, as the whole of the mortar is pressed back into the wall with a square tool or fillet for a distance of about ¼ inch. As the facing bricks must be square on all edges, the quality of the work is manifestly high; the wall has the special character of bricks set into a mass of mortar rather than of brickwork stuck together.

Flat Jointing.—A smooth flat joint is required for neatly finished internal work which is not to be covered with plaster or wainscot; for external work the flat joint should be slightly indented at the top and bottom to press the mortar behind the actual edges of the bricks.

Keyed Pointing.—Lines or keyed grooves are sometimes struck

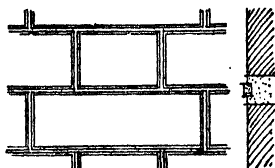

FIG. 75.—Flat Joint, keyed.


FIG. 76.—Grooved Pointing.

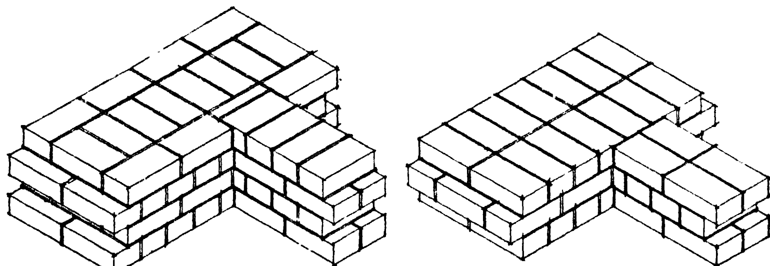
on the flat joint with a tool to emphasize the joint and to compress the mortar (see Figs. 75 and 76).

Tuck Pointing.—The superfine effect of gauged brickwork is simulated by tuck pointing ordinary brickwork (Fig. 77). After raking out the loose mortar in all the face joints and making up the surface with pointing, a groove is cut, and a narrow artificial joint of putty is dexterously tucked into each of the bed and upright joints. Good tuck pointing

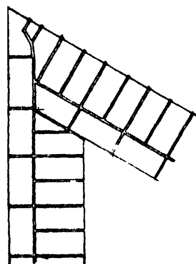
demands skill and accuracy, and is popular with craftsmen and the public because of its neat effect. Its virtue, however, so readily cloaks faulty brickwork that it should be looked upon with suspicion. Tuck pointing is the only kind that is effective in repointing old walls, whether of good or bad brickwork.


FIG. 77.—Tuck Pointing.

Junctions.—Walls are joined at right angles by the alternate insertion of the stretchers and headers of each wall. The stretching courses on the main wall are opened to form a quarter brick recess to receive the headers of the entering or cross wall, and as the heading courses of the main wall are not recessed the stretching courses of the entering wall butt against the face. The bond of the entering wall is set out from the angle so that a sound junction is built up. Fig. 78 illustrates the junction of a one-brick wall with a two-brick wall in English bond.


FIG. 78.—Junction in English Bond.

Toothings.—When a main wall is built and prepared for extension, or for the insertion of a cross wall at some later time, the recesses that are left in the alternate courses are called *toothings.*


FIG. 79.—Acute Angle Junction.

Angular Junctions.—The rules that apply to junctions at right angles also apply generally to junctions at obtuse or acute angles, the bonded ends of the interlacing courses being cut as necessary. In an acute angle junction the presence of a joint resembling a woodwork mitred angle must be avoided. The courses should overlay one another and be alternately trimmed. The external face courses will work themselves out to the angle. The end brick of each course is formed out of a whole stretcher cut to the acute angle. Fig. 79 shows an acute angle junction in 14-inch walls in English bond, alternate courses being reversed. In obtuse angle junctions the external angle is formed on squint brick stretchers, which cross each other, and the internal angle with a bird's-mouth header with a trimmed bat in alternate courses. Fig. 80 repre-

sents two obtuse angle junctions in 14-inch wall in English bond, the stretching course being outside in one case and the heading course outside in the other.

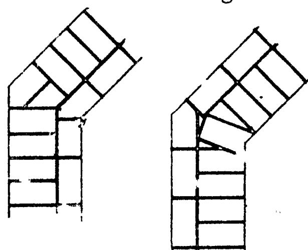


FIG. 80.—Obtuse Angle Junction.

Hoop Iron Bond.—The junctions of walls not erected simultaneously are strengthened by the employment of long strips of hoop iron, which are laid for half their length in the main wall, the remainder being built into the added portion. The hoop iron is 2 inches wide by $\frac{1}{16}$ inch thick, and is tarred and sanded.

Chases.—The junction of new work with an old wall is effected by means of a continuous chase or recess, so that in settlement the new wall may not draw away from or crack the old work. Pipe chases in new walls should be properly built square recesses, maintaining the bond.

Racking Back.—If the full length of a wall is not built at once, the work should not be left off with a vertical end, but stepped or racked back at an angle, so that a vertical line of junction shall not be created when the work is continued; this secures a more even settlement, and may save the foundation from cracking when the weight of the new portion settles down.

Fixing Timber to Brickwork.—It is improper to build timber into the substance of brickwork, as the dampness of the mortar shrinks and decays the wood. Wooden plates for the ends of floor joists should be carried on corbels of brick or stone, or supported on iron brackets built into the wall.

Fixing Blocks.—For the purpose of attaching joinery to brickwork, fixing blocks, slips and plugs are used.

Wood Bricks.—The term *wood brick* explains itself, and refers to a piece of wood sawn to brick shape, which is bonded to the surface brickwork as the work proceeds, in order to provide a substance into which nails can be driven for fixing joinery such as skirtings and window frames. A wood brick is, however, larger than a brick by the full thickness of the upper and lower mortar joints, and is kept in position by friction with the rough surfaces of the bricks. The effect of moist mortar would be to swell the wood, which afterwards in shrinking would get loose.

Porous Concrete and Brick Fixing Blocks.—Other fixing blocks are of concrete of various kinds, some patented and others often made on the job of coke breeze, or are bricks made with a mixture of sawdust, which burns away in the kiln, and produces a porous brick which will take in nails. Such fixing blocks are fireproof, and avoid the risks which attend the use of wooden fixings near flues.

Slips.—Long narrow wood slips of the full thickness of a mortar bed can be built in, instead of wood bricks, to afford ground for nailing.

Plugs.—Holes are also cut into walls after erection, and filled up with wooden plugs driven in and cut off level with the finished surface to provide for fixing fittings, care being taken to avoid flues and chimney breasts.

SPECIAL AND ORNAMENTAL BRICKWORK

SPECIAL BRICKWORK

There are fashions as to the appearance of brickwork which demand the use of specially made narrow bricks in elevations. The object generally is to imitate the effect of ancient work, either with a narrow brick and wide joint or by a rather thicker brick with rubbed edges and a very fine joint. Purpose-made bricks are manufactured to meet these demands, and their use for the surface, in conjunction with bricks of standard size for the rest of the wall, materially affects the bond.

Thin Bricks.—Where thin bricks are used for facing ordinary brickwork, the joints mentioned below must be duly considered.

Bond.—Three courses of bricks at 2 inches thick will bond with two courses at 3 inches, but there is no bond in the intermediate course. Fig. 81 shows how the bonding is effected, but it will be seen that there is a proportion of headers in the facework which are half bricks or bats.

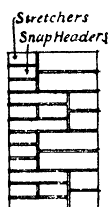


FIG. 81. Bond for Thin Bricks.

Mortar Joints.—Although the bonding of the brickwork may not be disturbed theoretically by the use of bricks differing in thickness for the outside and inside, the difference in the thickness of the joints is harmful to the integrity of a wall, because there is more mortar in one part than another, the mortar being subject to settlement under compression, which the bricks are not.

Extra Thickness.—In narrow piers and short lengths of wall built up of differing qualities of brickwork, some additional thickness should be provided to meet the loss of soundness in bond. In estimating the thickness of brickwork requisite for carrying a given weight, the facing, when not entirely integral with the wall in all respects, should be excluded from the calculation.

Glazed Brick Facings.—The difficulty entailed by the use of narrow facings also attaches to the use of glazed brick facings, which are seldom of the same *gauge* as stock bricks. Glazed bricks are as a rule fuller in size than the standard, and require a narrow mortar joint. The excess of size should not be considerable, or the trouble of unequal settlement in the front and back of the wall will be set up, and it is bad brickwork to snap the headers to avoid a difficulty.

Bricks of Special Shapes.—Purpose-made shapes are manufactured in all classes of bricks used for facings.

Obtuse angles, or *squint quoins*, are required for angular projections, *bird's-mouth* for internal angles, *bevelled-bricks* for finishing off plinths or off-sets, and *bull-nose* for the rounded angles of piers or doorways. In all these shapes the bond may require alternately shaped headers and stretchers. Stops which combine the normal with the special shape of the brick will be required for ends and returns to form the return angle.

ORNAMENTAL BRICKWORK

Moulded Bricks.—Moulded bricks are manufactured of accepted profiles for strings, cornices, and cappings. The moulded portion is

additional to standard size in order to provide for proper bond. Owing to the wet moulding and subsequent burning of moulded bricks, there is a tendency to irregularity in the continuous lines of a moulded course. The use of cut and rubbed bricks, set in fine mortar, is preferable for architectural features.

Profiles.—In cast moulded bricks, simple forms of large sectional profile can be advantageously used in large masses of walling with ordinary brickwork and mortar joints. Large ovolos, cavettos, and beads were the only sections used in mediaeval moulded brickwork, without any attempt to disguise the customary width of the mortar joints.

Rubbers.—The fine quality bricks which are made of specially washed clays for cutting and rubbing are called *rubbers*, and are made without frogs. They can be cut with a saw and reduced in shape, or gauged to sizes, by rubbing on a flat stone table. Fine mouldings are worked, and carved panels are executed in this quality of brick.

Putty Joints.—Gauged brickwork is set out with very fine joints of thin lime putty; cut and rubbed or gauged work is a refinement of the materials and workmanship of ordinary brickwork.

Architectural Features.—The subjoined notes relate to the architectural features coming under the head of ornamental brickwork.

Rusticated Quoins.—Projecting blocks, in imitation of stonework rustications, should be executed in gauged brickwork, having sufficient extra size in the bricks to occupy, together with the thinner joints, the average dimensions of stock bricks.

Strings.—Projecting strings, whether plain or moulded, require that the projecting portion should be an extra to the normal size.

Projecting angles containing the mitre may necessitate bricks of very unusual size.

Cornices.—Brick cornices cannot have the sudden overhang that is possible in stonework where the projection is balanced by the weight of the stone bedded in the wall. Brick projections must be gradual owing to the limited bed of each member.

Weathering.—All the horizontal surfaces of brickwork exposed to rain need protection by copings or weatherings.

Strips of lead built into the wall are required for covering all rubbed brick strings and cornices, and add to the expense of this class of work.

Pilasters and Caps.—The bonding of projecting pilasters needs careful attention. The width of the pilaster with the consequent position of two lines of closers, one near each edge, and the projection which affects the internal bond, should all be set out in full size.

Carving.—Carving in brickwork is executed on the finished wall. As the material is very fragile, projections must be kept down. The positions of all the joints, vertical and horizontal, of necessity assert themselves in the carving. Where projecting carving occurs, the fine joints of the gauged rubber brickwork are set in shellac. The work is built and bonded in simple blocks, to be shaped afterwards by the carver. The material hardens with exposure to the air, and should be treated as an ornamental luxury.

CHAPTER VII

MASONRY

By W. Douglas Caröe, M.A., F.S.A., F.R.I.B.A.

Preliminary

Definition. — Masonry is the art of building in stone. Unlike the art of building in brick, wherein an even sized and homogeneous material is employed, masonry is capable of infinite variety, depending not only upon the quality of the stone used, but also upon the method of using it. Success, in which due economy of material and labour has an important share, largely rests upon experience in connexion with the stone employed. It will thus often be found that a local mason, accustomed to handling local material, is more expert than a hand more deft with the actual tools, but without training in the best use of that particular stone. The study of local methods, especially those dating back a considerable time, is thus strongly recommended before a given stone is used either locally or transported to a distance.

Architectural Expression in Masonry. — There is a greater power of architectural expression latent in stone than in any other building material. It is possible in these notes to give the rules underlying sound masonry construction; but the full development of expression is a matter of individuality founded always upon sound construction and well considered use. Whatever be the style adopted, a competent architect will succeed in preventing a building from having the appearance of being turned out by a machine. The avoidance of purely mechanical effects in masonry should thus have the constant attention of the student. The misuse or mishandling of material is incompatible with a successful result.

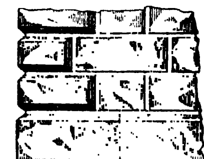


Fig. 82.—Ashlar Walling with rebated Joints and Moulded Quoins.

Methods of expression in masonry are generically twofold:

(1) Through the architectural forms into which the stone is shaped.

(2) Through the handling of the stone itself, comprising—as well as the shape—the superficial texture given to it, and the method of setting it together.

These two methods of expression may be complementary or may be definitely opposed to one another. If associated together, when in opposition the result is sure to be bad architecture.

Thus, regular rusticated stonework (Fig. 82), applied to a freely designed building of Gothic type, would be as inappropriate as the construction of the Parthenon in random rubble (Fig. 83).

Scale.—Methods of expression and scale are closely interwoven, and *scale* must always be regarded as one of the most essential elements of successful architecture.

KINDS OF MASONRY

Soft and Hard Stone.—Masonry may be broadly subdivided into soft stone masonry and hard-stone masonry, the former being called *freestone, i.e.* one allowing itself to be freely converted. These divisions naturally approach one another in practice, although obviously there comes a point when the use of a very hard stone, in a manner in which a softer one would ordinarily be employed, becomes non-economical, extravagant, and inappropriate. The important deduction follows that the designer in masonry ought to study the quality of the stone proposed to be used, and adapt himself accordingly in producing his design. A design prepared for Bath stone cannot be right if executed in hard granite or schist, although it may be possible.

Choice of Treatment.—No rule can be laid down for the choice of the best type of masonry applicable to any individual stone. It is well to study old buildings in the neighbourhood of any quarry as probably affording the surest guide, both as regards economy in use and general fitness.

CLASSIFICATION OF MASONRY

Whether in soft or in hard stone, masonry may be roughly classified either as *ashlar* or as *rubble*, but between the two are many gradations. Ashlar and rubble are almost invariably used in some combination.

Rubble.—Rubble is composed of large and small irregular stones used indiscriminately, either as they come from the quarry or broken by a hammer as the work proceeds to make them fit with one another better. If brought to the wall face they may be roughly worked or not worked at all. There are various different kinds of rubble, differently named in different localities. The names most generally in use are given in the following notes.

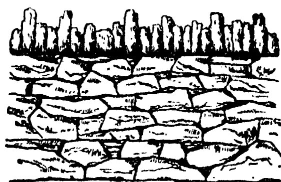


FIG. 83.—Random Rubble Walling with Rubble-on-edge Coping.

Random Rubble.—The stones lie together at random, as in Fig. 83, being selected to fit according to the skill of the mason, and the interstices are filled with spalls from the stone and mortar. In this work a stone which approaches horizontality should be laid horizontal. For architectural purposes the strength and solidity of a random rubble wall depends

(1) upon the quality of the mortar;
(2) upon the use of long bonding stones at frequent intervals;
(3) upon the solid filling in of all interstices.

It is important that all stones should be well wetted before use. This assists the mortar to cling to them. To ensure solid filling, grouting in with liquid mortar every few courses is frequently adopted. Many walling stones are absorptive, or porous, and specially so under protracted heavy wind pressure in exposed situations. It is specially important in such circumstances that the walls be well filled. The same is obviously the case when walling has to carry much weight. In building with rubble all stones should be surrounded with a pad of mortar. Humps or edges of the stone touching other stones under or over them may, under pressure, cause fractures in the wall.

Dry Rubble.—It is possible by skill and experience to build a strong wall of this kind dry, *i.e.* without mortar. Such walls are very serviceable and economical as fence walls. Good examples are found in Cumberland, Westmorland, Derbyshire, and other hilly districts, and some such *dry* walls have probably stood for centuries.

Level-bedded Rubble.—On account of the risk of fracture mentioned at the end of the last paragraph but one, rubble walling can advantageously be brought up to level beds (Fig. 84) at frequent intervals, from 12 or 14 inches to 2 feet, or 2 feet 6 inches or thereabouts, according to the size of the stones used. It is usual to grout in at every level course in such case and to insert good bonders either above or below the level course. The strength of the wall is much increased by this process.



FIG. 84.—Random Rubble Walling built in Courses.

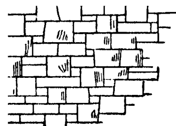


FIG. 85.—Flat-bedded Rubble.

Flat-bedded Rubble.—In many districts the stones are quarried with a fairly level bed. In such cases their use is much simplified. In flat-bedded rubble (Fig. 85) the ends of the stones are not necessarily made vertical, nor are the horizontal beds continuous. Small stones and spalls are used freely.

Squared Rubble (Uncoursed).—Squared rubble has squared joints and beds, the latter laid horizontal (Fig. 86). It is specially adapted to laminated stones, requiring little labour in reduction to a level bed. Work of the kind is frequently coursed, but the courses broken at irregular intervals by *snecks*, or taller stones than usual.

Squared Rubble (Coursed).—As shown in Fig. 87, this is similar to the last-mentioned variety, but is brought up at intervals to level beds as

described for random rubble. In both coursed and uncoursed squared rubble, vertical joints higher than one course are permissible, but they should not exceed two courses in height.

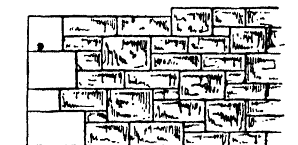


FIG. 86.—Squared Rubble Walling with Ashlar Quoins.

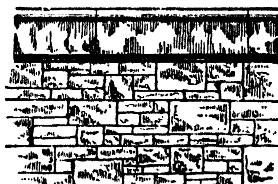


FIG. 87.—Squared Rubble Walling built in Courses, with Saddle-back Coping with Roll.

Regular Coursed Rubble.—Squared stones are used in continuous courses, but the height of the courses varies materially (Fig. 88). The more irregular their height the better the effect produced.

Coursed Header Work.—Squared header stones are used as bond at frequent intervals to form a good bond, and the spaces between them are filled with smaller stones laid with horizontal beds.

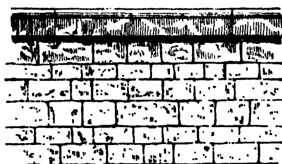


FIG. 88.—Regular Coursed Rubble Wall.

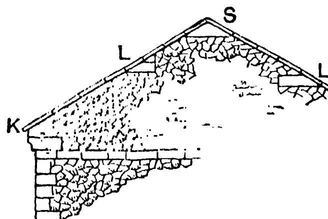


FIG. 89.—Kentish Rag Work.

Rag Work.—This is built with stones in small pieces in irregular shapes and dressed with a hammer (Fig. 89). *Close picked* work is fitted together with more or less care. *Rough picked* has wide spaces filled with spalls. Kentish Rag is frequently thus used, hence the term, but many other stones can be employed.

Dry Rubble Ashlar.—When a very hard impervious stone of laminated character is available, the face work is sometimes laid dry and sloping outwards, the bedding mortar being kept back about 6 inches from the face. This is found to secure a very dry wall, but requires special experience and skill. A thin wall is not possible in such construction.



FIG. 90.—Hammer-dressed Ashlar.

Block in Course or Hammer-dressed Ashlar.—This is a class of masonry intermediate between rubble and ashlar (Fig. 90), and differs only from the latter in that the beds and joints are not so neatly or accurately dressed, while

the face is formed by a mason's hammer. The courses are often not continuous, as in Fig. 86. This class of work is much used by engineers.

Ashlar.—This class of masonry consists of squared blocks of stone, tooled to a true face upon five sides out of six at least (Fig. 91). If the wall is built of solid ashlar, with occasional through bonders, the sixth side will also be tooled in the case of the through stones. While the courses are continuous, it does not follow that they are necessarily all of the same height or that the stones are of the same length. This should occur only in rusticated work, where it is intended to obtain architectural expression from the formal treatment of the joints themselves. Where, on the other hand, the wall face is flat, even in a formal building, better scale will be obtained by diverting attention from extreme regularity of jointing.

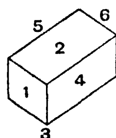


FIG. 91.

Proportions of Stones.—It is a rough rule that the length of a stone on the bed should not exceed three times its height, and that its depth into the wall should not be less than half of its height. The latter part of the rule may be held to be binding generally, but the former will depend widely upon the character of the material. Hard level-bedded rock, such as the igneous formation of the English Lake District, may be used freely with length eight or ten times its height.

Coursed Ashlar.—This variety consists of blocks of the same height in each course. It is the most expensive form of stonework, owing to the waste of material and labour in reducing all stones to the same height. There is never any occasion to adopt it unless—

(1) The emphasis of the joints, as by rustication (see Fig. 82, p. 84), is intended to be a feature of the building.

(2) The stone is being reduced by machinery.

In the latter case a monetary saving is effected generally at the expense of the building.

Random Coursed Ashlar.—The variety so termed consists of coursed ashlar with varying depths of course and lengths of stones.

Compound Walls.—It is seldom that a wall is erected of solid ashlar throughout its whole thickness. It has become a custom to build compound walls by using ashlar only as a facing, and backing it up with bricks or rubble masonry, as shown by Fig. 92.

Brick ashlar is the name given to ashlar backed with brick, as in Fig. 93. If the wall be thick there will be no "throughs." It is better (but not essential) that the stones should have a height equal to an exact number of brick courses. Brick-on-edge can, however, be easily adapted, or small bricks

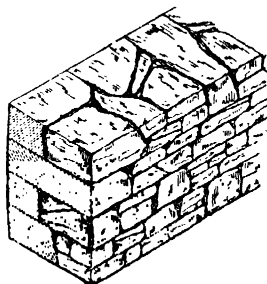


FIG. 92.—Rubble-backed Ashlar.

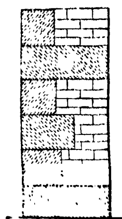


FIG. 93.—Brick-backed Ashlar.

here and there inserted to overcome difficulty. In such case the brick on edge or varied sized brick course should pass through the wall. Cutting bricks to make up courses should be avoided as introducing a ready opportunity for careless workmanship.

Rubble Ashlar.—In work such as that shown in Fig. 92, the horizontal beds of the ashlar should be dressed throughout, but the vertical joints need not be dressed for more than about 4 inches from the surface, after which they may taper with advantage. The ashlar in the same course should extend unequally into the core, with occasional long headers, not necessarily *throughs*.

Flint Work.—Building in flints is a special craft, and reached its best development in the eastern and southern midland counties, where it can best be studied. The "suction" of flint is not good, in other words, mortar does not readily adhere to it, and its security depends largely upon the irregularity of the surface. Thus very round or smooth flints or worn pebbles are not good in use.

Flints are frequently used chiefly as a facing, the core of the wall being filled in with chalk, broken brick, rough stones, etc. The longer flints should be picked out and used frequently as bonders. There can be no doubt that the early flint builders sometimes erected wooden screens, and treated the walls as a form of lime concrete, faced up with flints, kept in their place by the screen while the mortar was setting. This is a good method. Flints used as a facing to a concrete core will be found very satisfactory and strong. The timber screen is not a necessity if the walls rise only at short intervals, allowed to set as the work proceeds. Great care must be taken in such work that the concrete core does not swell in setting.

Round, Snapped, and Squared Flints.—Flints may either be used round, as found in chalk pits, or *snapped*, in which case the snapped face is used outwards. Both are used at times indiscriminately together. Flints are sometimes *squared* as well as snapped, but this is a much more costly type of walling, generally used by the mediæval builders to fill in architectural patterns formed in the stone. Excepting when using squared flints, the mediæval builders invariably let the mortar cover the face of the flints, and plastered over the whole. The plaster surface has in most cases worn away by exposure. Squared stones are occasionally used, alternating with square patches of flints, and a chessboard pattern results.

Stone Bonders.—Irregularly disposed stone bonders, showing on the face, are frequently used to help the bond of flint work. This type of work occurs specially in districts where old buildings, such as monasteries, have been demolished, and stones of various shapes and sizes have become available. In work of this kind any stone having a horizontal bed should be laid horizontally, a rule to be observed in all rubble building.

Roofing Tile Bonders.—Roofing tiles can also be effectually built into a flint wall to form a bond, either coursed at intervals or irregularly. If coursed, several courses should be used together. They add great strength to the wall.

Bastard Masonry.—The casing of metal framed structures with

stone is a familiar example of bastard masonry, and need not be discussed in this chapter.

Bastard Lintels.—One phase of modern masonry of a bastard type may be referred to here, viz., the formation of stone lintels upon a concealed steel frame. This is frequently resorted to over shop fronts in order to obtain a long sham lintel of stone. As the coefficients of expansion for iron and stone vary considerably, the construction is not good. The method is to fix rag bolts in the stone by running them with molten lead, and to bolt these on to the sustaining steel frame or girder. The stone is trimmed to fit the flanges, and the space between the stone and the girder should be run in with cement. Failing other means, this can be done by boring holes in the top flange of the girder. The rag bolts ought to be of gun-metal, but iron is often used. The life of such constructions has not yet been tested.

MASONRY METHODS

BOND, JOINTS, AND POINTING

Bond.—The character of the bond in all kinds of masonry is of first importance. On the face, the vertical joints should break upon every stone, as in Fig. 88. Weakness is immediately set up by cross beds and joints, and consequently these must be avoided both in ashlar and in rubble walling. The effect is the same when long vertical stones are used with a number of horizontal ones butting against them (Fig. 94).

In a re-entering angle, where the courses are continuous, it is usual to pass the stones alternately behind one another (Fig. 95, *a, b*). But where the courses are not continuous, this should be done as often as possible, and solid bonders inserted at intervals, depending upon the depth of the courses adopted (Fig. 95, *c*). When the re-entering angle is an obtuse angle, every third course should be on the solid across the angle, as in Fig. 96, *a*, and the other courses bonded, as in Fig. 96, *b*. Butt jointing, as shown in Fig. 96, *c*, should be avoided, as slight irregularities of building cause the joint to open, and the angle is favourable to the entrance of water.

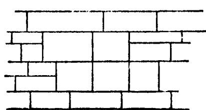


FIG. 94.

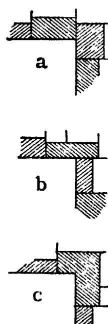


FIG. 95.

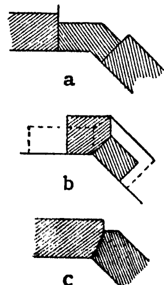


FIG. 96.

The bond across the thickness of the wall is also of great importance.

Throughs.—Through bondstones, or *throughs*, except in comparatively thin walls, should be avoided when the wall is cored with rubble. As the core is apt to settle down more than the face, if the through is broken

by being unsupported in the middle, the tie is lost, and an unfilled joint is set up. It is better to use long *headers* at intervals extending into the core. The beds of headers should be carefully worked to avoid their resting upon points. Headers or throughs should be deep on bed so as to carry weight. They should be avoided if absorbent stone is used.

To build up each face of a wall independently and to fill in a rubble core, trusting only to headers for bond, is not good work. The stones should be laid in irregularly from either side and overlap where possible.

The area occupied by cross bonders is sometimes given as from ½ to ¼ of the area of the wall face. But this must obviously vary with the type of walling employed. In some types of stone the header courses can be continuous. Through bonds should never be used when the stone is porous, as they conduct moisture through the wall. The practice of leaving the ends of throughs projecting from the wall and working them off afterwards is injurious to the masonry and should not be allowed.

Natural Bed of Stone.—It is of first importance in dealing with stone that its structure in the quarry be considered. With few exceptions rock has a natural bed, which must not be confused with its lines of cleavage (see Part III.). When used in walling the natural bed should lie at right-angles to the line of principal pressure. In a wall the natural bed will thus be horizontal, but in an arch in the direction of the centre. The more detached and the smaller a stone is in weight-bearing use, the more important is it to observe this rule. A window mullion, therefore, should not be set with its bed upright. It is better to joint it in short lengths. In the case of a markedly laminated stone used for a projecting cornice, or other overhanging feature, it may be advisable to lay the stone with bed upright and at right angles to the wall face. If a stone so used is exposed to the weather on its upper surface, it should be protected on the top by lead or asphalt, or other suitable material. In some stones it is difficult for the user to detect the natural bed. In such cases the bed of each stone should be marked by the quarryman as part of his work.

Ashlar Bed Joints.—It is important that the bed joints of ashlar (or *beds*, as they are usually termed) should be worked true, and specially so when a fine joint is desired or much weight is to be carried. With a hollow or concave bed joint the weight is apt to be thrown on the edge (*c*, Fig. 97), and when weighted the stone is easily *flushed*. Flushing occurs more readily in stones not set on their natural bed, as, for instance, in upright bedded mullions. To avoid flushing it is often useful to rake back the joint and point up after the mortar is well set. Lead should on no account be used for bedding or jointing stones. It has been proved to reduce materially the bearing power of the stone.

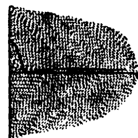


FIG. 97.—Hollow Bed Joint.

If ashlar is set with a wide joint, the risk of flushing and cracking due to irregularities on the part of the mason is considerably reduced. In certain types of work, wide-bedded and jointed ashlar is very effective.

Fig. 98 shows a bed joint worked "slack," with the object of saving labour. Being only supported at back and front, the stone is apt to break as shown. A convex bed joint will lead to the same result.



FIG. 98.—Slack Bed-joint underpinned with a Spall.

The greater the weight to be carried the more importance attaches to the accuracy of the masonry. Otherwise what are known as bedding cracks will occur. If less pronounced, these will show themselves by the joints opening; if more so, by fissures through the stones themselves.

Mortar Beds and Joints.—Mortar is applied between the stones in horizontal joints, called *bed joints*, or usually *beds*, and in vertical joints, simply called *joints*.

Ashlar and Rubble Walls.—While ashlar requires a comparatively small amount of mortar, rubble needs a large quantity, and the strength of a rubble wall will largely depend upon the quality of the mortar and the care with which cavities are filled up. Spalls of stone, bedded in mortar, should be used freely for filling such cavities.

Compound Walls.—Uniformity of construction in every kind of walling is of great importance. All walls consolidate and settle down when weighted. This is immaterial if they settle homogeneously; inequality of settlement, however slight, produces cracks, and may result in insecurity. The backing of walls should, theoretically, have joints equal in number and thickness to those on the face. In actuality this is not found to be essential, provided cement or sufficiently quick-setting mortar be used, in order that the joints may become consolidated before pressure comes upon them. Compound walls should have a minimum thickness of 16 inches, but if so thin they demand careful execution. The rougher the character of the stone used for the core the thicker must be the wall. Local practice is generally a safe guide to determine the minimum thickness for a weather-proof wall in any particular stone.

The building of a compound wall always demands care with regard to the under-mentioned important point:

For every bed in the ashlar there may be two, three, or more beds in the core, whether this be built of brick or rubble stone. As the wall goes up and the weight increases the compression of the rubble or brickwork becomes greater than that of the ashlar. The unequal compression throws the weight on to the ashlar skin, and may cause that to crack or bulge away from the core. This will obviously happen the more readily if the ashlar is built with a close joint, which allows little room for compression, or if the work is built quickly. Therefore the following rule may be laid down for building in rubble ashlar:

If fine jointed ashlar be desired, the core should be built in cement, or the whole built slowly to allow the mortar to set before the wall is heavily loaded.

If the core backing the ashlar be of brick, as in Fig. 93, it is obviously wise to lay the bricks with a finer joint than the ashlar.

Thickness of Beds and Joints.—As masonry joints, like those of

brickwork, may be of various widths, the thickness of the beds and joints must depend upon individual taste. In ashlar work the tendency of the mason is to reduce them, not always wisely, to a minimum. The thinner the bed the more accurate must be the workmanship, and the more difficult is it to fill the bed. If not filled, capillary attraction may be set up or the stone may be more easily broken. Within limits, wide jointed work is preferable for strength and surety of building. The mediæval builders frequently used oyster shells to determine the width of their joint. Wren employed these also, but sometimes also wood wedges. Any such expedient should be removed before the work is set, as being apt to create bearing weight upon one small area.

Lime Mortar.—The method of mixing lime mortar suitable for masonry depends largely upon the qualities of lime and sand available, as well as upon the nature of the stone itself. Fine mortar free from grit is necessary with fine joints. Mason's *putty*, formed with lime and water, is frequently used for fine jointed ashlar, but should never be used for rubble. Putty on the outside and mortar within is sometimes adopted, but should be avoided. Walling mortar should be used for work whose joints are ¼ inch wide or more.

Wren used at St. Paul's Cathedral almost pure gypsum (plaster of Paris) for setting facing stones, and mortar composed of about 3 parts of pure lime to 1 part of fine clean sand for the core of the walls. This unusual combination has produced a hard setting and imperishable mortar.

Lias Lime Mortar.—Certain sandstones and oölites are stained by being set in *lias mortar*. Bridgewater lime is injurious to some beds of Bath stone, and specially to the blue stone. No rules can be given upon so far-reaching and complicated a question, here referred to as a warning that local experience alone is a safe guide in an important detail, which ought always to be well considered.

Cement Mortar.—Certain stones, especially oölites and some sandstones, do not take kindly to Portland cement. Unsightly stains occur, and sometimes these are accompanied by early decay. No rule can be given, as the result depends upon the quality both of the stone and of the cement. Whitewashing the built-in faces of the stone, when to be set with a cement mortar core, is sometimes resorted to, but cannot be uniformly relied upon.

Portland cement is apt to set the more rapidly as it is nearer to the air, and as it alters its bulk in the process of setting it is not a suitable material to place in any large quantity in direct association with the air, unless careful precautions are taken. Cement pointing, then, often shows hair cracks upon its surface, which suck in the moisture. When cement is used, as small a surface as possible should therefore only be exposed. Cement is often used in large quantities to fill the superficial cavities of a rough-built wall, and sham joints are then pressed upon it or thin trowel lines drawn to make believe that there is more stone than really appears. This is the worst kind of workmanship, as using a good material to the worst advantage. When a large surface of cement is exposed it will generally be found that after having thoroughly set the cement is adhering

only to the stone by the irregularities of the surface of the latter and not by cohesion. Water is therefore being constantly sucked up between the stone and cement, subjecting the former to incipient decay. Cement, when used for pointing, should be kept back, and in no case allowed to cover any part of the surface of the stone, unless used as a continuous cement plaster, in which case special precautions are necessary.

Cement is a material very easily used, and therefore much liked by artisans. It is specially deceptive, because its worst qualities and deficiencies often do not develop until two, three, and sometimes four years after its use. Up to those periods it appears to be acting to the best advantage. It is obvious that cement should never be used for repairing the surface of decayed or flushed stone.

Pointing.—The strongest result is generally secured by pointing up the work as it proceeds with the actual mortar bed used in bedding. A sound homogeneous joint is thus secured. But as a building of any size generally occupies some part of the winter in its erection, this process is not always possible on account of the effect of frost. Work is thus generally left to be cleaned down and pointed at completion. It is in such cases necessary, while the mortar is soft, to rake the joints and beds well back (¾ inch at least), so that there may be an ample bed of mortar in the pointing, and that the junction with the set bed may be well removed from the air whereby they will combine better. Joints should be well wetted before being pointed—an important precaution generally neglected.

If good mortar is used it is best to keep the pointing somewhat back from the surface. If weak absorptive mortar is employed, then point out to the face and finish flush.

The mortar, whether of lime or cement, should never be allowed to cover any part of the surface of the stone, even if this is irregular. When it so covers the stone, capillary action is set up, and decay may result. Cement should never be used for pointing any form of stone naturally softer or more absorptive than cement when well set. Apart from chemical action, which may or may not be injurious to the particular kind of stone used, the cement bed holds up the moisture, and tends to cause decay or cracking away under the action of frost. Fig. 99 shows a section of a not infrequent result of cement pointing. Cases have occurred where it has caused superficial decay in stone, which before its application had lasted many centuries.



FIG. 99.

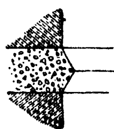


FIG. 100.

On no account should a projecting or mason's V-joint be tolerated (Fig. 100) in cement or mortar. These are often used by unskilled masons on the false assumption that they throw off the wet.

Work on the Solid.—The solid bonding and jointing of masonry is of first importance in every particular.

The stopped ends of mouldings or projecting features should be on the solid of the piece of stone from which this feature is reduced. The

portion shaded in Fig. 101 is out of one stone, and the piece upon the return wall is called a *solid stopping*.

Mitre joints in external or internal angles should never be used, but the member turned round the angle on the solid with a solid mitre (see Fig. 102). If a comparatively small string course is stopped against a large stone, the solid stopping should either be let into the stone or, better, a small piece of the string course should be worked on the stone, so as to avoid a butting joint.

If two or more mouldings meet one another at any angle the stones on which the meeting takes place should be solid. Exceptions sometimes occur in connexion with elaborate examples of carving or niche work, but they should only be treated as exceptions to a firm rule for well designed masonry.

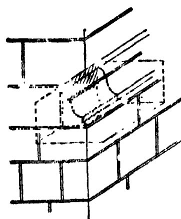


FIG. 101.

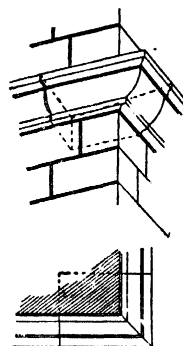


FIG. 102.

Connexions to Strengthen Joints.—Greater strength is sometimes required than is afforded by the adhesion of the mortar and the weight of the stone, as, for instance, in the case of copings, or of isolated stones such as pinnacles (not kept in place by surrounding masonry), or of traceries, or of masonry exposed to sea waves.

Dowels.—These consist of small blocks of hard stone or slate or metal (not iron) let into the beds or joints (Figs. 103 to 106). They

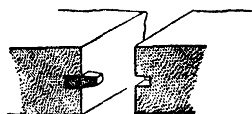


FIG. 103.—Horizontal Dowel.

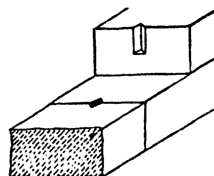


FIG. 104.—Vertical Dowel.

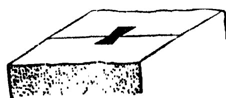


FIG. 105.—Dovetailed Dowel.

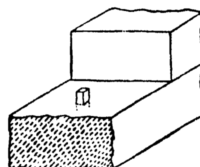


FIG. 106.—Bed Plug.

should be of sufficient section to prevent easy fracture. One-inch slate cubes are often used, set in cement, and when used in the beds are called *bed plugs* (Fig. 106).

Grooves and Dovetails.—Sill stones or others, which have no superincumbent weight to keep them in place, are well secured by cutting corresponding grooves in each joint, and running in same in cement or molten lead. If these are cut to a dovetailed section the best result is obtained (Fig. 107).

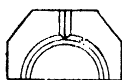


FIG. 107.

Joggles.—A *joggled joint* is one by which a portion of one stone is worked to fit into an adjoining stone This is frequently used to strengthen arches, and various forms are used, as illustrated in Fig. 108, *a, b, c.* Care must be taken that the joggle is strong enough to resist pressure in the particular stone used. Given an equal weight to sustain the size of the joggle will depend upon the strength of the stone.

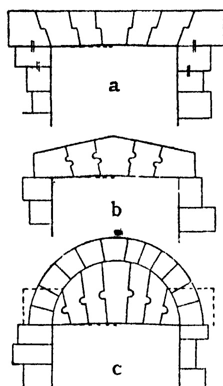


FIG. 108.

Various devices of the kind of more or less intricacy have been adopted in the past, and can be designed to suit the occasion. Spanish masonry, which generally exhibits much technical skill, may be studied with great interest upon this point.

Rebates.—Rebated joints are made similar to their wood counterparts in joinery work, as described and illustrated in Chapter VI., Part II.

Metal Dowels, Cramps and Plugs.—Iron should on no account be used to tie stones together. The iron subjected to moisture will rust in the stone and its consequent expansion will cause cracking and dislocation.

Sir Christopher Wren's rule was not to use iron within 9 inches of the external face of a wall. But this is hardly safe. The three upper tiers of Wren's spire of St. Bride's, Fleet Street, London, were once rendered insecure by being lifted bodily up nearly an inch by the rusting of the octagonal iron ties built around the spire at the springing line of each tier to bind the whole together.

Bronze, gun-metal, or copper (generally referred to as "metal" in contradistinction to iron) may be safely employed in stone work; and it is usual to run in metal cramps, ties, and plugs with lead, a metal which is easily fluxed, and does not result in staining of the stone.

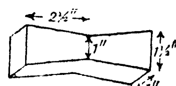


FIG. 109.
Lead Cramp.

Gun-metal Dowels.—Long gun-metal dowels (say 12″ × 1″ × 1″) are used to secure comparatively slight features such as finals, vases, pinnacles, which are designed to stand detached without support except at their base.

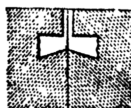


FIG. 110.
Lead Plug.

Lead Cramps and Plugs.—Lead can be used effectively for cramps, but on account of the pliable nature of the material it should be in stout sections. Lead cramps are dovetailed thus and should not be less than the dimensions given in Fig. 109. Lead

plugs (Fig. 110) are formed by pouring molten lead into plug holes (generally dovetail shaped) formed in the stones. The holes slope downwards so that the lead may run at once into the ends and corners. It is important that the latter should be filled up completely.

FACING, DRESSINGS AND DETAILS

Facing.—The surface of masonry is *faced*, or finished by means of a tool, in various ways. It may be axed, boasted, chiselled, dragged, hammered, punched, rubbed, or otherwise treated. The mason's axe is seldom used now and may be said to be obsolete. It was applicable only to comparatively soft stone. It may be desirable to emphasise some special feature of a building by tooling it in a special manner, marking it out from the rest. Such treatment is generally appropriate to formal building only, and may easily become a false method of expression, destructive of architectural harmony and repose.

Boasting.—The term *boasting* has a different meaning in different parts of the country. It generally applies to the rough reduction of stone to a form to be subsequently moulded or carved, but in some districts it is applied to final tooled facing of a comparatively rough character.

Hammer Dressing.—This is the reduction of the surface by means of a mason's hammer. It is very frequently used in engineering works (Fig. 90).

Chiselling or Tooling.—Facing by means of a chisel or tool obviously varies greatly according to taste, and no rule can be laid down for guidance. The *bats* of the chisel may be evenly disposed or irregular, may be across the stone, along it, or in a transverse direction. Drafting the edges of the stone is sometimes adopted, vertically along the beds, horizontally up the joints, with chisel marks of even width (Fig. 111). This method was widely employed in the eighteenth century.

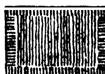


FIG. 111.

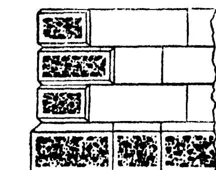
The breadth of the mason's chisel varies inversely with the hardness of the stone. A useful form of chisel, largely employed in the thirteenth and fourteenth centuries, is a clawed tool. This has a serrated edge, and although generally employed now as a reducing or boasting tool only, it is capable of producing an attractive finished face.

For some very hard stones a pointed tool only is used, and the work is called *picked* or *pecked.* This tool sometimes takes the form of a pointed hammer, and in this form is used also for hammer dressing.

A much used modern method of reducing the softer limestones is to be deprecated. This consists in roughly reducing them to a fair face, smoothing them down with a drag or mason's comb and adding upon the flat surface any form of tool marks that may be desired. A waste of labour (although not supposed to be so) results in insipidity.

Rustication.—Ashlar is sometimes irregularly *punched* on the face, leaving either an irregular projecting or a recessed surface. This treatment may be extended over the surface of the wall or confined to coins

or string courses, as in Fig. 112. In either case the beds and joints associated with such work are generally chamfered, rebated, or moulded (Fig. 82, p. 84). With rebated ashlar the wall face is sometimes treated as at the back of the rebate and sometimes as at the front. The difference in effect between the two is material.


FIG. 112.—Ashlar Walling with chamfered and rusticated Quoins and Plinth.

Rubbing and Polishing.—Rubbed or polished work is generally reduced by sawing to a fair face, which is then rubbed smooth by friction with another piece of stone, either of the same or different quality, according to local circumstances. It is very customary to rub sandstones with the same or a coarser stone, and stones so treated are frequently described as "sanded."

Machine Work.—Machines exist for sawing, moulding, rubbing, and polishing stones, without any intervention of direct hand labour. These are economical in extensive works, but tend to produce a mechanical result.

Moulding.—Moulding tools are made of various shapes to suit the mason's needs, flat tools being almost invariably used in contradistinction to the curved gouges in use with timber.

Dragging.—Common and cheap work in soft stones, whether in facing or moulding, is frequently left from the drag.

SOME MASONRY DETAILS

Weathering.—The operation of *weathering* is the dressing-off of the upper surface of a stone to a slope, slight or not according to the requirements of design, so that rain may not rest upon it. Weathering should be applied generally to all architectural forms and details, to carving as well as to moulded work. Thus, the lowest part of a circle cut in the surface of a wall at right angles to its face should not be horizontal but slightly adjusted so as to be weathered, and if the circle be moulded the hollows of the mouldings capable of holding water should be run out.

Throating.—The term *throating* means the cutting of a groove or throat on the under side of that part of a stone projecting over a wall, so that rain may fall freely from the projection (see Fig. 113, *a*, *b*, *c*).

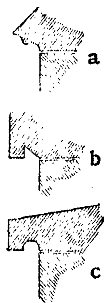


FIG. 113. Throating.

Arrisses.—An *arris* is an external edge in masonry and should never be at a less angle than 90 degrees. If an arris becomes less than a right angle it is called a *feather edge*, and is generally to be avoided. When a feather edge occurs at the top of any pyramidal form—as at a gable point—it is best rounded off.

Corbels.—Corbels are stones projecting from a wall in order to form a support. They may be of one or more courses deep, as required, and in most types of architecture have been treated, when in view, as features of interest (Fig. 114).

Level Beds.—If it be desired to reduce the span of an arch, the lower courses are often *level bedded* (Fig. 115). In that case these courses really form a succession of corbels, the top one of which is radiated to the striking centre. To avoid flushing of the weak arrisses, it is well to keep the mortar in the upper joints back during erection and to point up afterwards. Level bedded springers are often dowelled or plugged with dove-tailed lead plugs for greater security.

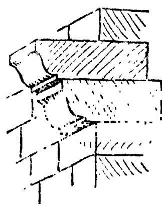


FIG. 114.—Corbels.

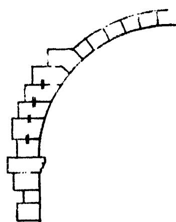


FIG. 115.—Level Bedding.

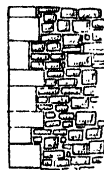
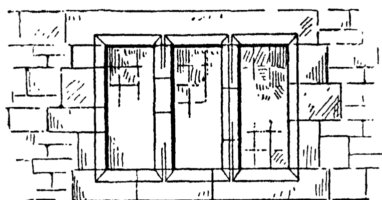


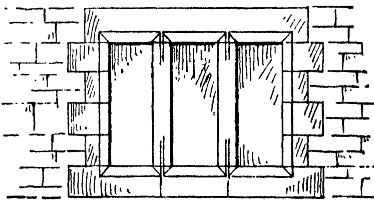
FIG. 116.—Quoining.

Quoins.—Also known as *coins* and *coigns*, these are the corner stones of buildings and are important in bonding walls together (Fig. 116). Large and sound stones should be selected for use in quoining; and if a weak rubble is used for walling, the internal angles should also be crossbonded with larger stones. The rougher the class of walling the more essential it is to quoin it with squared stones, the longer the better. If suitable for conversion for the purpose the same quality of stone as for the walling is best used. It is sometimes necessary, however, to introduce a different kind of stone, but the effect is never so satisfactory.

The mediæval builders invariably used *irregular quoins* (Figs. 89, 116, 116*a*), whether to angles, or to windows, doors, and other architectural



Mediæval



Modern Mechanical

FIG. 116*a*.—Quoining.

features. They seem to have used the stones just as they came to hand, and generally with excellent judgment. Rubble walls being essentially unmechanical in effect, most buildings gain greatly in appearance and scale by this free treatment, although it would be inapplicable to a building in which formality was made a feature.

The use of *cog-wheel* quoins (Figs. 116*a*, 117) in other than formal and symmetrical building is necessarily inappropriate and should be studiously

avoided. In Fig. 116*a* the same window is drawn both freely and mechanically for comparison. In works of repair, where it is necessary to introduce new quoin stones to windows and other features of an ancient building, the substitution of cog-wheel for irregular quoins is destructive of the character of the building.

Jambs.—Jambs are the legs or sides of windows, doors, niches, and openings generally. Where wood window or door frames are employed, the jambs are often formed into reveals (Fig. 118). The thickness of the stone in front of the check must depend upon design. Good bond is all important, and frequent long headers are desirable. In consequence of the slamming of doors it is often advisable to dowel jamb stones. Jamb stones sometimes consist of long stones on end, often only in one piece, the whole length of the opening. This is bad building.

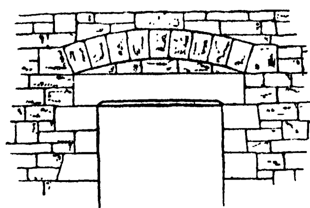


FIG. 117.—Stone Lintel with Relieving Arch.

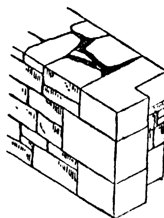


FIG. 118.—Stone Jamb with Reveal.

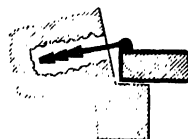


FIG. 119.—Hook Stone.

Hook Stones.—Where doors are hung directly from the stone, ***hook stones***—large stones into which the hooks for the hinges are leaded—are built in at the proper levels (Fig. 119). It is better to fix the hooks after the work is completed, as they are thus more accurately fitted in connexion with the door. When leading iron into stone, care should be taken that the whole of it is covered with lead, and that the perimeter of the hole made in the stone is rough.

Window Sills.—The sills of windows should be weathered sufficiently to throw off quickly the water falling upon them from the non-absorbent glass above and thus to prevent it from soaking into them unduly. Sills are frequently made to project, in which case they are often throated so as to throw off their drip from the wall below (Figs. 120, 113, *b*). Window sills should be bedded hollow by leaving out the mortar from the bed under them, except at the ends under the jambs, until the work is set, when the bed can be filled up. As the weighted jambs are apt to compress the part of the wall under them, the sill must have room to settle down with the jambs. The wall under the middle part of the sill, not being weighted, does not necessarily settle down with the jambs. Cracked sills are very common, and constitute an obvious weakness to be guarded against, as water penetrates the fissures, and may saturate the core of the wall below.

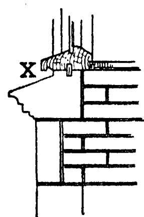


FIG. 120.

Where windows are large it is advisable to build a concealed invert

arch under the sill from jamb to jamb. This helps to keep the unweighted work under the sill homogeneously compressed with the jambs. The inverted springer of such an arch should be carefully designed and bedded (Fig. 121).

Where a wooden sill (which should always be in oak, teak, chestnut, or mahogany) is bedded upon a stone sill, a metal *water bar* or continuous tongue (X, Fig. 120) is inserted into corresponding grooves cut into both stone and wood, with the object of preventing wet from driving through the joint. It is a valuable device also to throat the wood sill thus, the wood sill being bedded in white lead.

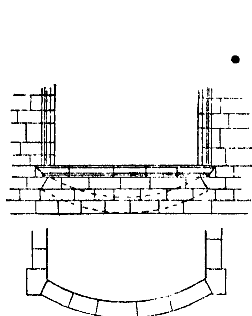


FIG. 121.—Invert Under Sill.

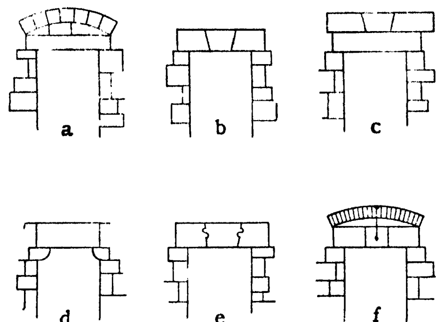


FIG. 122.

Lintels.—A lintel in masonry is a horizontal piece of stone resting on the jambs of a door or window, or spanning any opening in a wall, and serving for the support of superincumbent weight.

Lintels have sometimes to be assisted in carrying the weight placed upon them, or adapted to openings which the stones used are not long enough to cover, as represented in Fig. 122.

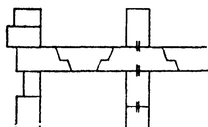
When a relieving arch is used (Fig. 122, *a*) its span should not be less than that of the opening. The space between the soffite of the relieving arch and the top of the lintel should be left vacant until the building is nearly completed. A relieving arch should only be used when sufficient abutment is provided for it. The same applies if the lintel has a radiating key, as Fig. 122, *b* (in which case it becomes an arch). If abutment is not available, then the lintel must be strong enough to sustain itself.

Wren, being unable to procure stones in one piece long enough to bridge the voids he wished to cover at St. Paul's Cathedral, adopted the device of hanging up the centre stone from a concealed brick arch by an iron rod, as at Fig. 122, *f*. The ingenuity of this method hardly excuses its adoption. It would have been better had Wren used brass or copper, gun-metal not then being available.

String Courses.—Intended primarily to serve the practical purpose of throwing water off a wall at intervals of its height, string courses (Figs. 101, 102, p. 95) are often employed to strengthen a weak wall, in which case they should be cramped by metal and well bonded. They are frequently used as an architectural feature to influence the proportions of a building.

Lacing Courses.—Walls built of flints or irregular small stones without good bond are frequently strengthened by building in *lacing courses* at intervals, consisting of horizontal bands of ashlar, coursed rubble, tile or brick (Fig. 89, p. 87).

Mullions.—These are the vertical divisions of some forms of windows (Figs. 116*a* and 123). They should have dowels at every bed. One-inch cubes of slates are best. Window sills should never be jointed underneath the seat of a mullion.


FIG. 123.

In Gothic work the mullioned windows were invariably strengthened by a system of threadled ironwork, consisting of stanchions and saddle bars, and forming an integral part of the architectural scheme too often omitted with loss from modern work of the kind. The iron bars were also used to secure the leaded glazing by means of lead tape or copper wire. When such bars are used it is most important to treat the ironwork so that it will not rust and burst the stone. This is best done by polishing it, and painting the bright surface with two coats of good red lead before setting, and fixing it in carefully cut mortice holes with well killed cement. Gun-metal or bronze can be substituted for iron with advantage if means permit.

Transomes.—A transome is a horizontal bar across a window used to subdivide its height. Transomes require to be very carefully bedded, being generally both weak and inelastic, and thus very apt to break if one end is pressed down more than another. Thus, if a jamb is formed of short stones and a mullion of long stones, the jamb will tend to compress the more, and the transome must break. Transomes, if not in one piece, have to be jointed over a mullion, which is not good construction. If sufficiently deep, the difficulty is overcome by jointing them, as Fig. 123. The keys can then be dropped in after the building is fully weighted.

Traceries.—Divisions forming geometrical or other set patterns in windows of an ornamental character are called traceries. The best method of jointing traceries must depend upon their design, the rule being to secure strength without waste of material. All traceries should be jointed on the solid with dowels, as for mullions.

Arches.—The subject of arch construction is discussed in Chapter IX. Therefore only one or two special points are here mentioned. The central stone, or key, of masonry arches is frequently emphasised by projection or ornament. If used in genuine Gothic work the key, being at the point of the arch, must have a double curvature. In this form, the key is difficult to work and to set accurately. Further, it is apt to break or become displaced if adequate accuracy be not observed (Fig. 124, *a*), or if the weights above it are not equally disposed.



FIG. 124.

In most of the best examples of mediæval work the keystone is replaced by a vertical joint at the point of the arch (Fig. 124, *b*). This has been found to be the best construction.

Labels.—A label is a projecting cover moulding, primarily devised for the practical purpose of throwing off the water, but is often used merely to create a shadow or enforced line. In external work the label should be cut out of the solid at the apex, as in Fig. 124, *b*.

Copings.—A coping is a course placed upon the top of a wall to prevent the entrance of wet. Copings should be in stones as long as possible, so as to reduce the number of joints through which water may gain access to the masonry. When dressed, the upper surface should be weathered, and projecting horizontal copings are best throated. Coping stones are often cramped or dowelled together, or united by cement or lead plugs. In good work the beds of copings are dowelled to the wall below.

Fig. 87, p. 87, represents a *saddle-back coping*. This is frequently also rounded, as in Fig. 84, p. 86. Fig. 125 shows a *feather-edged coping* weathered to throw the water back. *Parallel coping* (Fig. 89, p. 87) has the upper and lower surfaces parallel, and should only be used when it is laid at an inclination, as on gables or ramps

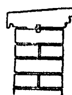


FIG. 125.

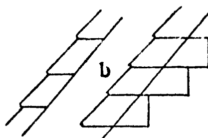


FIG. 126.

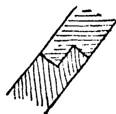


FIG. 127.

The *saddle* or *apex* stone (S, Fig. 89, p. 87) is the solid horizontal bedded triangular stone, in which copings meet at the apex of a gable. The *kneeler or knee stone* (K) is the springing stone of a gable or ramped wall, and should be at least 2 feet 6 inches long on the bed and dowelled. If there be a corbel stone under it, that also should be a long stone, and dowelled on its bed into the stone below. The pushing out of the knee-stone is a frequent defect in gabled buildings. Therefore in a tall gable or ramp, one or more *bond stones* (L) are built in to assist in preventing the coping from sliding. The larger this stone is on the bed the better. Lacing stones are used in connexion with it, but are not necessary, although often advisable on a tall gable if rubble or flint walls are used. In the best Gothic work the stones (L) were not necessarily placed exactly at the same level if no lacing course was used.

Raking copings are sometimes fixed with a horizontal joint, which should, however, be avoided unless precautions are taken to avoid a *feather-edge* (Fig. 126, *a*). Every stone of a horizontal bedded coping is sometimes bonded, as in Fig. 126, *b*. A rebated joint, as Fig. 127, is also used.

Copings for Rubble Walls.—Dressed copings are frequently used for rubble walls, as in Fig. 87, p. 87. Rough flattish stones are frequently used and are called *toppers* (Fig. 83, p. 85). These are more or less alternately high or low, or sometimes an extra high stone occurs every few feet. Too much cement should never be used in such construction. It is apt to shrink, crack, and suck in the water.

Plinths.—The plinth is a feature introduced to give an appearance of stability and should be devised with that end in view. The treatment generally may therefore be on a broader scale than elsewhere. The greater the weight to be borne the more careful should be the bedding. This caution is important in regard to plinths.

Steps.—As steps necessarily have no building weight upon them except at their ends, the same considerations apply to their construction as to window sills. Wide flights especially have to be prevented from apparently rising in the centre.

A flight of steps of considerable width (varying according to the strength of the stone) can be constructed by tailing only one end into a weighted wall, provided the front edge of each step rests upon the step next below it and the whole of the lowest is supported. The tail depends upon the width of the flight, and to some extent upon the weight on the wall. If the steps are moulded as K (Fig. 128), the tail should be on the solid, as drawn. Steps are generally rubbed or polished.

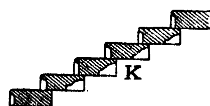


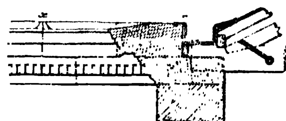
FIG. 128.

In all buildings, breadth of effect is obtained by keeping stone stair treads wide and risers very limited. In monumental buildings this is essential. Narrow treads, specially in external flights, are destructive of dignity, as at the Capitol in Washington.

Small circular staircases are constructed with a continuous central newel worked on the solid of each step. This is a very strong form of construction, and additional strength is secured if the beds of the newel are dowelled. Staircase construction in stone admits of much variety and ingenuity, and in these aspects is a matter of special design, outside the scope of this work.

Stone Pavements.—Stone pavements should be constructed of hard material, and, where variety of materials is used for the sake of design, it is important that they should assimilate in hardness. Hard and soft materials should never be used together. The effect of cement upon some stones (see p. 94), and specially limestones, should be considered in laying pavements, these being generally only in thin stones. It is often advantageous to bed hollow in plaster of Paris. If a concrete bed be used, it ought to lie several months, until efflorescence has ceased, before stone in a decorative pavement is laid over it, otherwise unsightly staining and possibly decay will occur.

Cornices.—A cornice is a moulded or ornamental course on the top of a wall. Cornices are intended to protect the wall from wet, and on this ground are best weathered and throated. They are also used artistically to give shadow. A sufficient part of the cornice should rest upon the wall to more than balance the projecting portion. It is very usual to cramp the stones of a cornice together with metal, or to adopt one or other of the devices already mentioned for strengthening the joints. *Saddling* the joints


FIG. 129.—Stone Cornice. Sectional Elevation showing Saddled Joint at *x*.

(x, Fig. 129) consists in leaving the stone high at the joint to throw off the water. This device was frequently used by Wren. In some ancient Irish work, a seat is made at each side of a joint and another stone is bedded upon the seat, whereby the joint is quite protected.

A cornice may form the topmost member of a wall or may have a blocking course over it. In the former case, and if the gutter at the back is near the top of the cornice, a *raglet* may be required to receive the lead, or a dovetailed groove the asphalt.

Grooves for Asphalt.—If asphalt be used to form a gutter or flat behind stonework, a dovetailed groove about 1½ inches deep should be cut to receive the top of the skirting (see Fig. 130). Such grooves should slope upwards and be filled only with asphalt; cement or mortar pointing should be avoided. A gutter is sometimes formed on the top of a cornice or eaves course. If the stone is soft the hollow should be lined with lead or asphalt. Cement should never be used.



FIG. 130.

Cornices or similar projecting members at any height on a building are advantageously covered with lead or asphalt. In either case the covering material must be secured at the back, so that water cannot enter. If asphalt be used, the back is let into a dovetailed groove cut in the stone or brick next above the cornice (Fig. 131), and the front edge is kept in place by a continuous dovetailed groove about ⅜ inch at the mouth, and kept sufficiently far back not to weaken the stone unduly.

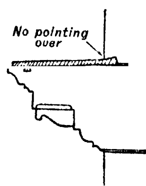


FIG. 131.

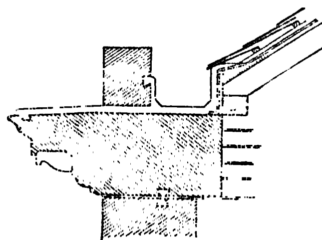


FIG. 132.

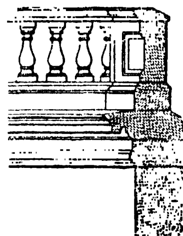


FIG. 133.—Cornice and Balustrade.

Blocking Course.—The blocking course should generally be dowelled into the cornice. Where gutters have the same relation to the blocking course as described above for the cornice, the same treatment will apply. Where the stone is of absorptive character the blocking course should have some impervious material either over or under it. An asphalt gutter is conveniently constructed, as shown in Fig. 132.

Balustrades.—In the balustrade shown in Fig. 133, the small columns, called *balusters*, are divided into groups by blocks called *pedestals*. Each baluster should be dowelled top and bottom.

Parapets.—A parapet is generally a solid wall, but may be pierced in a decorative manner. Economy is sometimes studied by erecting the parapet of thin stones and buttressing them at frequent intervals at the back. In such case every stone should be dowelled.

Buttress Weatherings.—These can be of various forms to suit taste and style. When weatherings of ordinary rake are used, an appearance of stability is obtained by making the rake of every weathering, as the work goes up, a little flatter than the last, whether the weatherings are blocked together or separated. The difference in effect and repose is obvious when this treatment and the reverse of it are set together (Fig. 134). The top stone of a weathering, especially when its slope finishes at the wall face, should be deeper than the others.

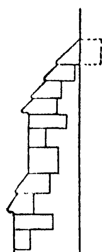


FIG. 134.

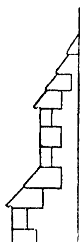


FIG. 135.

Fig. 135 shows a simple and effective method of setting out weatherings. After setting out the bottom member of each course, beginning from the bottom, the rake of that course is directed to the vanishing point of the top weathering.

PRESERVATION OF STONEWORK

As taken from the quarry, all stones have *quarry sap* in them, which generally makes them easier to work. After the exposure of a new surface to the weather, the stone tends to become *case-hardened.* Experience shows that if once the case-hardened surface is removed by decay or other influence, the stone below is apt to decay more readily. Hence the working back of decayed stone to a new surface is never a successful expedient, and may accelerate decay in the long run. Some stones, under the influence of the tool or polisher, form a skin or crust which peels off under weather stress. Purbeck marble and Kentish Rag sometimes exhibit this characteristic. Such stones should be tooled as lightly as possible with a very sharp tool.

The extensive use of coal, gas, and other such fuels to meet modern domestic and manufacturing needs, results in the diffusion of sulphurous fumes in the atmosphere much more freely than in the past. Building stones which may safely be used in a pure atmosphere are frequently unable to withstand the contaminated atmosphere of cities and manufacturing centres. This applies particularly to stone in which calcium carbonate is the chief binding material, the calcium carbonate becoming calcium sulphate (gypsum), which is slightly soluble in water.

The subjoined notes briefly describe various expedients tried either to prevent, or to arrest the progress of, decay in consequence of sulphurous constituents in the atmosphere.

Lime Washing.—A strong solution of quicklime, best used hot, is effectual for a certain period. It lays a fresh film of lime over the surface

of the stone, serving to protect, as long as it lasts unimpaired, the decaying surface below from atmospheric action. But it has no chemical action upon the stone; and as it readily absorbs not only the sulphur which would otherwise have passed to the stone, but also some of that already absorbed by the stone, it forms only a temporary shield, subject to the same decaying influences as the material protected. It destroys texture even in one coat, and its necessary renewal from time to time as a more lasting protective may deaden or destroy form also. If repeatedly applied it may form an unduly thick skin, which may fall away in large flakes, taking some of the decaying stone with it. In a pure atmosphere it may be said to be fairly effective, but less and less so as the atmosphere becomes tainted with sulphur. Lime wash alters the aspect of a building by destroying the texture and colour of the stone. From a flat white, when first applied, it soon becomes black in a smoky town.

Fluate.—This is a solution devised to prevent early decay in some of the more friable oölites. It renders stone less absorbent, and is not without effect when used with new stone. It has little value in arresting decay already established.

Barium Hydrate.—Employed in the form of *baryta water*, this is used with the object of chemically converting the gypsum (calcium sulphate) into barium sulphate, an insoluble material. A 3-per-cent solution only is obtainable, and thus a large number of coats have to be applied. Fifteen, with time between each to soak in well, are generally used, three coats per day being a maximum. The stone should be dry. The best result is obtained in warm, dry weather. Before application, the stone must be cleaned of all dust or loose or partly detached pieces by means of a hard bristle or wire brush. The beneficial effect of baryta water (apparently very marked at the outset, if the stone is of a suitable nature) is ephemeral, and the delusive character of the material thus renders it somewhat objectionable. Lime wash has been employed over stone first treated with baryta. This probably helps the baryta to be effective as long as the lime proves to be so, but at the expense of texture.

A bluish cloudy efflorescence marks for some months the application of baryta. Soot or lamp-black mixed with farmyard refuse, and set with a patent petrifying liquid, are sometimes adopted to hide this, but generally with indifferent results.

Baryta and Hydrofluosilisic Acid.—If between every two coats of baryta water a 1-per-cent solution of hydrofluosilisic acid be applied, a better and more lasting result is obtained. The treatment and protection of the stone as above described applies to this prescription. Care must be taken that the solution does not contain more than 1 per cent of acid.

As it is possible to break up stone by over-dosing it with baryta, caution has to be used. It is advisable in any case for any fresh sample of stone to be chemically tested before resorting to the process. Baryta and acid may be applied with a spraying machine or with a brush, according to convenience. Both are poisonous substances, and care must be used.

Hemingway's Siastic Solutions.—These require preliminary cleansing of the stone and dryness, as in the case of the baryta-acid treatment. Silicate of soda (solution S) is first freely applied by brush or spray, and after twenty minutes in ordinarily warm dry weather is followed by arsenic acid (solution A). Care must be taken that separate brushes or spraying machines, as the case may be, are used, as the solutions must not touch one another before they meet in the stone. Both are intensely poisonous, and the acid solution is destructive of cloth.

This appears to be the most effectual preservative of limestone hitherto invented, but its lasting quality has yet to be proved by sufficiency of exposure. In the case of sandstone or other stones deficient in lime, it is well first to treat them with several coats of transparent lime water, allowing the same to dry before applying the solutions. In some cases the A solution may be applied with better effect both before and after solution S, but for instructions on this and other points the patentees should be consulted. The Siasic solutions produce a pronounced but very varied efflorescence, which will, however, disappear after more or less exposure. If solution S be allowed to dry before solution A is applied, the discoloration is very marked.

Sundry Patented Fluids.—Zerelmy's fluid, the Stone Preservative Company's Fluid, Browning's Solution, and other trade compounds will be found more or less effective according to circumstances, but seem to have generally merely an ephemeral effect. The last mentioned appears to be the most satisfactory. Chemical analysis and constant observation can alone prove the efficiency of chemical application for preserving stone, the subject being yet in its infancy.

Paraffine Wax.—This is a preservative on somewhat different lines. The stone is cleansed by steam and then indurated with hot paraffine wax, the effect being to form a waterproof superficial skin, which presents a mechanical resistance to weather stress. The colour effect is apt to be unpleasing. The system, like most others, requires the proof of time before it can be fairly judged.

The Repair of Old Stone with New.—To fit successfully new pieces of stone solidly into old is not easy, and requires both skill and experience. The back of the stone should be grouted up, an air hole being required as well as a runnel for the grout. Patching may sometimes be possible, but where stone is much decayed it is best to replace each decayed piece wholly with new, taking care that the exact sizes of old and new correspond.

Cleaning of Stone.—In town building especially, it is usual to cover up new stonework with a composition of lime called *slurry*, or *sludge*, which protects it during the period of construction. The slurry is easily removed, without destruction of arrisses, or tool marks, as the scaffold comes down. The final pointing is generally done at the same time, and the whole of the work is of uniform colour. Smoke-begrimed buildings in our cities can be cleaned by exposing them to the blast of a steam jet. Sand blasting is also adopted, but as it tends to remove the surface it requires caution.

CHAPTER VIII

WALLS, PIERS, AND RETAINING WALLS

By Herbert W. Wills, F.R.I.B.A., and

C. Lovett Gill, A.R.I.B.A.

WALLS

Definitions.—A wall is a structure of stone or brick or other material serving to enclose a room, house, or other space, and in most cases to carry floors and roof.

The student will find it necessary to understand thoroughly the following terms and their meaning as applied to the walls of buildings.

Base.—As applied to a wall, the term *base* means the under side of the course immediately above the footings (Fig 136). In the case of a wall carried by a *bressummer*, it means the under side of the course immediately above the bressummer (Fig. 137).

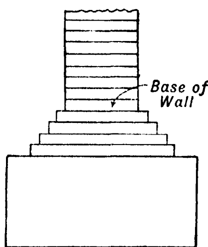


Fig 136.

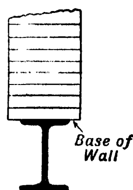


Fig. 137.

External Wall.—An outer wall or vertical enclosure (not being a party wall) of any building.

Party Wall.—A party wall may be either a wall forming part of a building and used for the separation of adjoining buildings belonging to different owners, or occupied by different persons; or a wall forming part of a building and standing to a greater extent than the projection of its footings on the land of different owners. The second definition means that the footings may stand on the land of an adjoining owner, without giving such owner any claim over the wall.

Cross Wall.—A wall between the party or external walls, and used in any part of its height for the separation of one part from another part of a building.

Party Fence Wall.—A wall not forming part of a building, and used for the separation of adjoining lands of different owners and standing on land of different owners.

Curtain Wall.—An external wall, supported by a bressummer of

steel, reinforced concrete, or other material, and carrying nothing but its own weight.

Sleeper Wall.—In the construction of most domestic buildings and those buildings having no basements, under the ground story it is usual to form a hollow space under the ground floor, and in order to reduce the span of the floor joists sleeper walls are constructed about 6 to 8 feet apart to support these floor joists. In building these in brickwork they are built "honey-combed," as in Fig. 138, where the portions hatched are open spaces, the object being to maintain the cross ventilation under the floors, and at the same time to reduce the cost. Where sleeper walls are built in stone they take the form of small piers built at intervals to support the wall plate or sleeper.

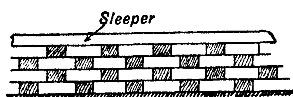


FIG. 138.

THICKNESS OF WALLS

This is the distance from one face to another measured horizontally across the wall. The rules applying to the required thickness of walls have been definitely settled in this country by the London Building Act of 1894 and the Byelaws of the Local Government Board. The London Building Act provides further that the thickness of the external wall in any story shall not be less than one-sixteenth of its height in a domestic building, and not less than one-fourteenth of its height in a building of the warehouse class.

The diagrams in Fig. 139 are drawn showing the working out of the various thicknesses of walls required for general building purposes under the London Building Act. For those of the warehouse class see London Building Act 1894.

TYPES OF WALL CONSTRUCTION

Concrete Walls.—In constructing walls of concrete great care should be taken in the quality of the materials used. The proportions of the concrete should not be poorer than 1 part of Portland cement, 2 parts of clean sand, 3 parts of coarse hard material, broken to pass a 2-inch ring.

Composite Walls.—A composite wall is one built of two or more materials, such as brick, stone, concrete, and tiles.

Brick and Stone.—In erecting a building with stone face, bricks are used in most cases for the internal backing of the walls to bring them up to the required thickness. In preparing drawings for such a building it is usual to show the depth of the stone joints, to correspond with a given number of brick courses, so as to afford the necessary bond with the brick backing. The depth of the stones or bed in plain ashlar work

Fig. 139.—Thicknesses of Walls for General Building Purposes, as required by the London Building Act.

will vary between 4½ to 9 inches, projecting cornices being generally tailed down by cramps or by bolts (see Fig. 140).

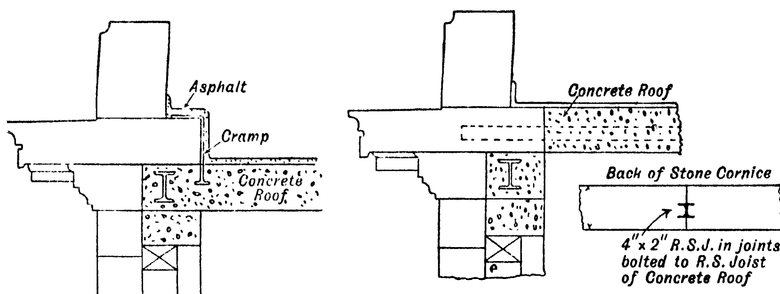


FIG. 140.

Brick and Stone with Concrete Filling.—This kind of wall is useful where great strength is required. Where brick and stone are expensive it is advantageously employed in the construction of piers to carry heavy loads, and which on account of architectural effect have to be very massive, as in the case of piers required to support the pendentives of a dome.

Brick and Tiles.—The use of tiles in brickwork was practised by the Romans in the construction of their walls—for the purpose of forming a tie across the wall—and the tradition now survives as a decorative feature in the shape of tile quoins and arches. This feature is still used in the position of a tie, but is not treated as a structional tie across the wall.

HOLLOW WALLS

The object in building a *hollow wall, i.e.* a wall having a vertical cavity in its construction running parallel to its external face, is to prevent the passage of moisture from the outside from penetrating into the building. The air space should be continuous throughout the wall, and the bond or connexion between the two parts of the wall should be of such material and shape as will prevent the passage of moisture.

The hollow space should be ventilated to carry off any moisture that may collect on the inside of the outer portion of the wall, and air bricks should be inserted in the bottom of the cavity.

The hollow wall is often arranged to begin on the damp-proof course, but it is better to continue the hollow for three or four courses lower, as in Fig. 141, so that any wet falling into the cavity may be well below the damp course, and this makes allowance for a certain quantity of fallen mortar to collect without destroying the damp-proof construction.

Hollow Stone Walls.—In a stone-built building it is usually found necessary to form a hollow space behind the external face for reasons similar to those applying to brick walls, and in exposed situations this is a necessity. A 4-inch or 9-inch brick wall is placed behind the stone wall, and the two walls are united together by iron ties similar to

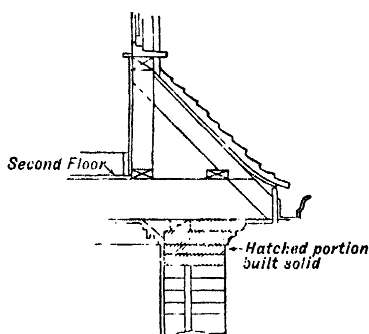
those used for brickwork, the chief difference being that the position of the ties must be worked in to suit the jointing of the stonework.

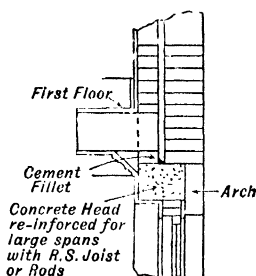
Hollow Brick Walls.—There are several ways of constructing this type of wall. Usually it is found necessary to make one portion thicker than another, and difficulty may arise in deciding whether the thicker or thinner portion should be placed on the outside.

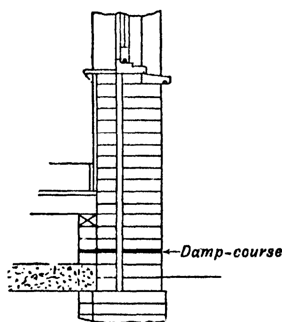
Hollow Wall with 4½-inch Portion Outside.—This method is undoubtedly the best where the building includes more than one story, the chief objection being its external appearance, the absence of headers in the 4½-inch external portion giving the wall an unpleasing and monotonous effect. Its advantage is that construction work, such as floors and roofs, can rest on the thicker portion of the wall, which, being inside, reduces the span.

Hollow Wall with 4½-inch Portion Inside.—The appearance of the thicker external portion is much to be preferred to the 4½-inch external portion, laid without headers, as mentioned in the preceding paragraph.

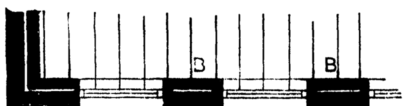
A method of getting over the structural objection to the placing of all the floor and roof loads on the thin inner portion is shown in Fig. 141. The first floor joists take a bearing on a concrete lintel over the windows, thereby transmitting the weight to the thicker outer portion of the wall. If this method is not adopted the whole of the weight of the floors would be concentrated on the 4½-inch walls at BB. A cement fillet should be placed where shown to







Hollow Wall with thin portion inside.



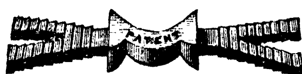
Key Plan showing Floor Joists.

FIG. 141.

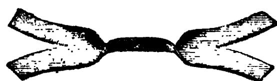
keep any moisture against the outside wall. The top of the wall where protected by the roof can be built up solid so as to distribute the weight to be carried over the whole wall.

Hollow Wall of Two 4½-inch Thicknesses.—This method should not be adopted except where the brickwork is only one story in height and built in cement. When the first floor is placed in the roof, the joists can be run over the whole wall, as in Fig. 141.

Bonding of Hollow Walls.—In order to secure proper strength in the wall it is necessary that the inside and outside walls shall be securely bonded across the cavity by ties, in order that they can be considered as one wall. The strength of a hollow wall will depend upon the nature of the ties employed in the construction. The best method, and the only one that gives the best results, is to provide galvanised iron ties with either a bend or a twist in the middle, so as to stop the passage of moisture along its surface (see Fig. 142).







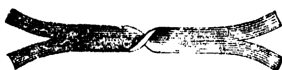
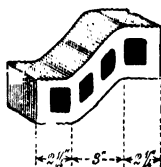


FIG. 142.

Spacing of Ties.—The iron ties should be placed 3 feet apart horizontally, and in every fourth course of brickwork, or about 1 foot apart vertically.

Bonding with Hollow Glazed Bricks.—Patent bonding bricks (see Fig. 143) are sometimes employed for tying the walls together,



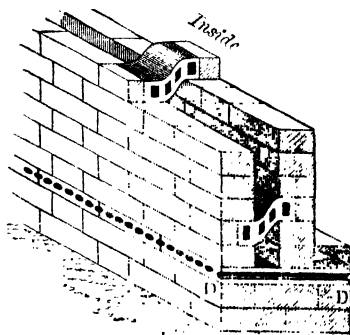


FIG. 143.

but have several disadvantages. Thus, they are liable to be cracked by a slight settlement of the building and therefore become useless; they are more costly and more difficult to fix than galvanised iron ties, and require more care to keep them free from mortar.

Walls on Sloping Ground.—The best arrangement for walls of this type is to form the foundation in steps so as to obtain a vertical thrust on the ground (Fig. 144). The wall itself may either follow the steps, or be made to run parallel with the slope of the ground, or be ramped up at intervals. When the last method is employed the points where the level is changed form convenient positions for piers, and enable horizontal joints to be used in the wall.

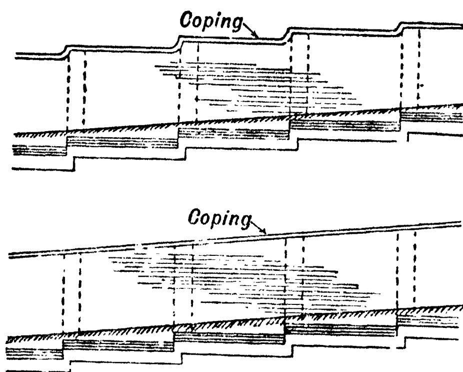
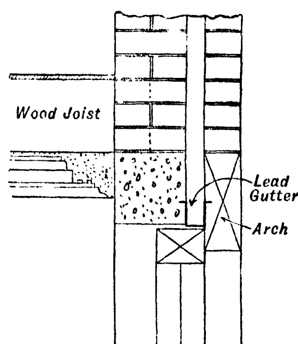


FIG. 144.

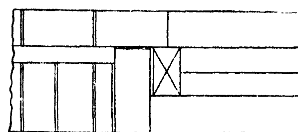
DOOR, WINDOW AND OTHER OPENINGS

The usual openings met with in the construction of buildings are those for doors and windows. Various methods are employed in spanning these openings either by arches or lintels.

In external walls of brickwork, openings are generally spanned by a brick arch either *gauged* or *axed*. The gauged arch should have a structural relieving arch on the inside.



Section



Plan

FIG. 145

Openings in Hollow Walls.—Wherever door or window openings occur in hollow walls it is necessary to protect the ends by building 4½-inch brickwork, as shown in Fig. 145, and the top of the frames must be protected by a piece of sheet-lead made in the shape of a small box-shaped gutter turned up about 2 inches into the brickwork at each side as shown, and extended beyond the frame 3 inches each side to throw any moisture clear of the brick backing below.

Openings in Glazed Brickwork.—Owing to the difficulty of cutting glazed brickwork, the method of constructing arches over openings is generally by using half-brick rings, keeping the joints as fine as possible on the *intrados*, and letting the cement or mortar fill the joint, which becomes wedge-shaped.

Stone Sills.—The use of stone sills on glazed brickwork has the disadvantage of preventing the rain from washing the surface of the wall directly beneath. The method shown in Fig. 146 has been found to obviate this

defect. A water bar is not necessary, as the curve of the brickwork starts from A. Bull-nosed bricks should not be used.

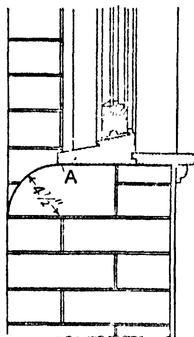


FIG. 146.

Concrete Lintels.—In order to reduce the cost and increase the facility of building, concrete lintels are often used, the surface of the concrete being kept back 1 inch from the face, and finished in Portland cement. One drawback to this method is that some of the light is lost in internal areas owing to the reduced area of reflecting surface, and another drawback is that the appearance of the lintel is not so good as that of an arch.

Jambs of Window and Door Openings.—The depth of the reveal in brickwork varies from 4½ inches to 9 inches, and in some cases the reveal is either omitted altogether or placed on the inside.

Window Reveals with Splayed Jambs. — Reveals with splayed jambs are usually adopted in the case of windows where a maximum amount of light is required, and where folding wood shutters are used. The arrangement is considered by some to be superior in appearance to that given by the use of square jambs.

Different Methods of Building Reveals. — The usual method of building a window reveal in brickwork is to allow a depth of 4½ inches for a cased frame and 2¼ inches for a solid casement. Sometimes a small reveal is built on the inside to allow a wooden outside frame, as in the Georgian type of window. Window reveals in stonework are built on similar lines, and in some cases the reveal stone is placed in position after the window has been fixed.

Door reveals are formed either by flush sides or with a reveal to take a solid wood frame.

Door Openings.—These are built to take either a solid frame, as in Fig. 147, or wood linings, as in Fig. 148, in which case they are

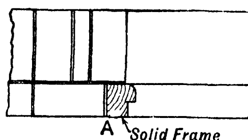


FIG. 147.

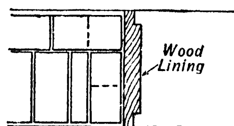


FIG. 148.

built square. In this method the frame is usually held in by wooden wedges, driven in at A (Fig. 147).

PIERS AND COLUMNS

Brick Piers.—As the result of the experiments carried out in 1893 by the Royal Institute of British Architects, it was found that the strength of piers was greatly affected by the internal construction. It

was also found that the closers at the angles constituted a source of weakness, but in order to obtain bond and flush sides, such closers cannot be avoided in practice.

The London Building Act does not allow any brick pier to be built to a height of more than six times its least width without having proper lateral support, but any such pier with proper lateral supports may have a height between such supports of not more than twelve times its least width, 14 inches being the minimum width permitted.

The weight in tons per square foot on the brickwork piers built in cement should not exceed the following values:

Blue brick	12 tons per foot.
Hard bricks . . .	8 ,, ,,
Ordinary brick . . .	5 ,, ,,

Stone Piers.—Wherever possible, stone piers should be constructed with horizontal joints only, each course consisting of one piece of stone. Each stone should have a short dowel at the centre to prevent any movement in the pier. This is obviously impracticable in the case of large piers, but in every case large stones should be used, dowelled or cramped together, and it is most important to keep the joints as fine as possible. The efficiency of the structure will depend to a great extent on the bedding of the stones.

The weight in tons per square foot on stone piers should not exceed the values stated below. The first figure may be taken for a fair quality of work laid in good lime mortar, and the second figure for best quality work laid in cement.

Rubble	5-15 tons per foot super.
Ashlar (sandstone) ¼ inch joint	10-20 ,, ,,
,, (limestone) ,, ,, ...	20-25 ,, ,,
,, (granite) ,, ,, ...	30 ,, ,,

Stone Columns.—A stone column free from defects, carefully bedded, and not exceeding ten diameters in height, should safely carry a load equal to one-fifteenth of the breaking load of stone of the same kind and quality. In no case should a load greater than 40 tons per square foot be placed on a stone column unless special precautions are taken as regards joints.

RETAINING WALLS

A retaining wall is a wall built to sustain the pressure of earth deposited behind it after the wall has been built. Face or breast walls built against a face of earth in its natural position are sometimes termed retaining walls, but this application of the term is not strictly accurate.

The theory of the stability of retaining walls is a subject discussed in Part IV., the present notes merely giving some typical examples of construction.

Plain Concrete Retaining Wall.—Fig. 149 represents the profile of a plain concrete retaining wall, proportioned in accordance with the practical rule of Sir Benjamin Baker, whose experience showed that in ground

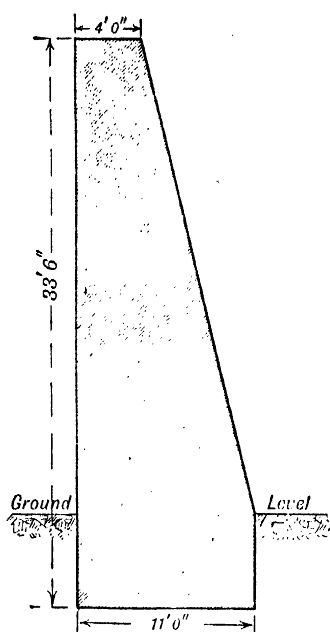


FIG. 149.

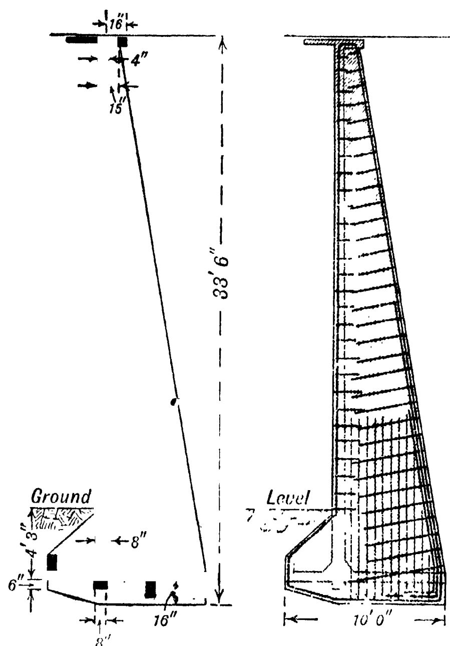


FIG. 150.

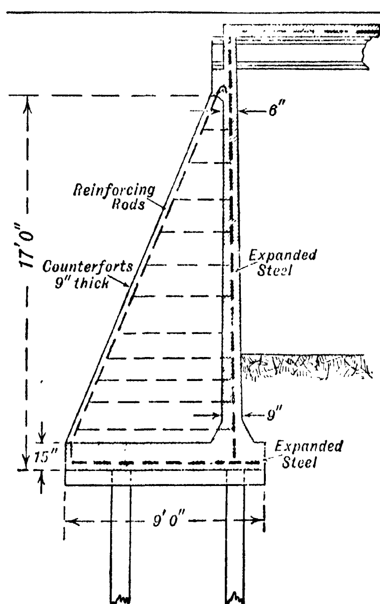


FIG. 151.

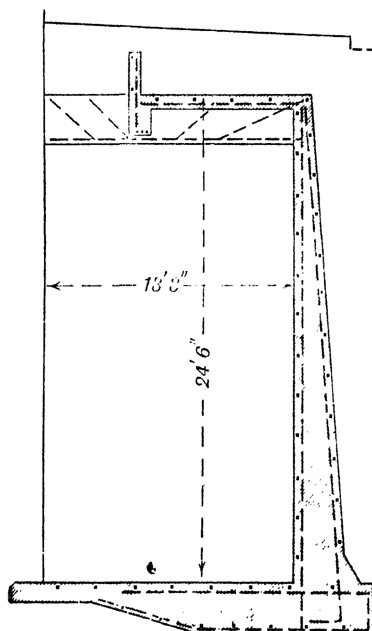


FIG. 152.

of average character the thickness should be one-third of the height from the top to the footing.

Reinforced Concrete Retaining Walls.—Figs. 150 to 152 illustrate the construction of three types of reinforced concrete walls.

Fig. 150 includes two cross-sections of a retaining wall, 33 feet 6 inches high, constructed on the Mouchel-Hennebique system for the King Edward Memorial Hall, Herne Bay. The wall consists of a vertical slab tapering from 8 inches thick at the base to 4 inches thick at the top, stiffened by counterforts spaced 14 feet apart longitudinally. One drawing is a section through the vertical slab and the footing, and the other is a section through the counterforts.

Fig. 151 is a section of a retaining wall built at Guildford in accordance with the Expanded Metal system, and consisting essentially of a vertical slab tapering from 9 inches thick at the base to 6 inches thick at the top, and stiffened by counterforts spaced 5 feet 6 inches apart longitudinally, the wall being 17 feet high.

Fig. 152 illustrates the type of retaining wall constructed in accordance with the Indented Bar system for the Royal Insurance building, Piccadilly, London. The wall proper is 24 feet 6 inches high, and its thickness 2 feet 6 inches at the bottom, tapering to 9 inches at the top. The thrust of the earth is taken by the vertical wall, and the horizontal slab occurs on the opposite face. The cantilever type adopted in this instance affords a clear space immediately behind the wall.

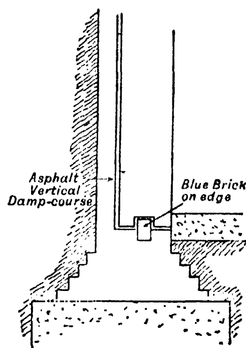


FIG. 153.

Foundation Wall acting as a Retaining Wall.—A precaution to be observed in building a foundation wall, that also acts as a retaining wall, is that the thrust of the earth at the back may cause the wall to slide in on the asphalt damp course before the weight of the superstructure comes upon it. This can be overcome by placing blue brick on edge at intervals along the wall, and covering all with asphalt (see Fig. 153).

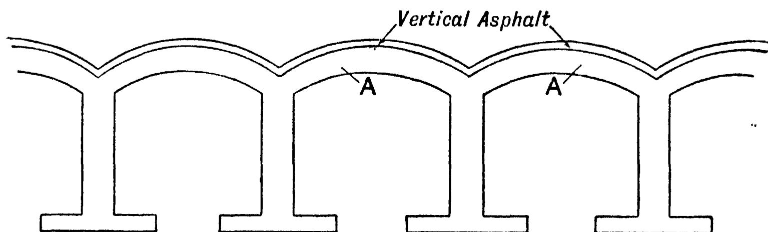


FIG. 154.

Retaining Walls to Vaults.—The most usual method at the present time is to do away with the curved back wall of the vaults, as at A (Fig. 154), and to construct a retaining wall, as at B (Fig. 155), the neces-

sary support being obtained by the division walls XX. The latter form is easier to construct and just as effective, but the arched form is useful

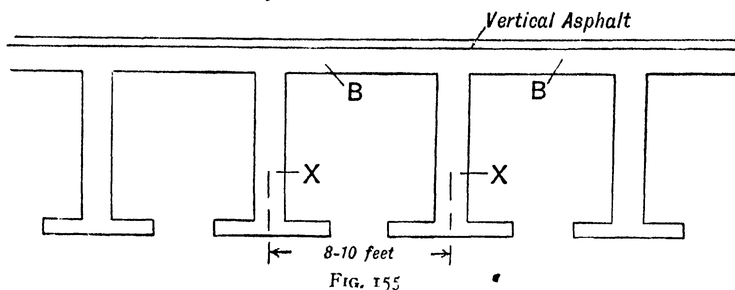


FIG. 155

FIG. 156.

in special circumstances. The division walls should not be spaced more than from 8 to 10 feet apart. Fig. 156 is a section giving details of construction for a vault of the form represented in Fig. 155.

CHAPTER IX

ARCHES, VAULTING, AND DOMES

By Alfred W. S. Cross, M.A., F.R.I.B.A.

ARCHES

Definition.—Designed to support the weight of the incumbent walling, an arch, whether constructed of brick, stone, or other hard material, consists of a mechanical arrangement of wedge-shaped blocks, placed over an opening, and upholding each other by the mutual pressure of their own weight, the structure being maintained in equilibrium by the resistance of the supports or abutments.

Technical Terms.—The technical terms used in connexion with arches may be explained as follows (see Fig. 157):—

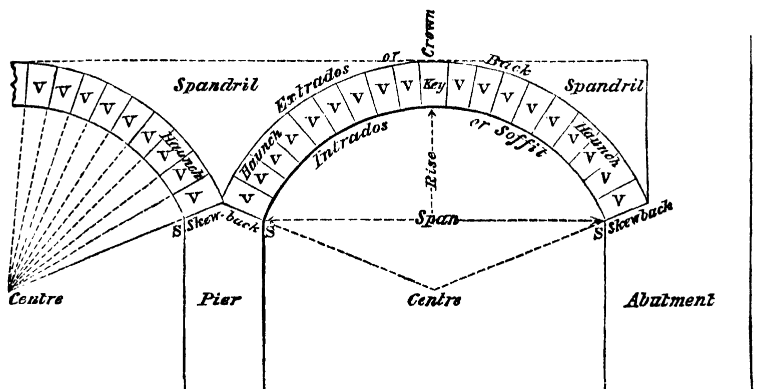


Fig. 157.—Parts of an Arch.

Voussoirs (vvv) are the separate blocks used in the formation of an arch, the central one at the *crown* being the *keystone*. The *intrados* is the under surface or *soffit*, the upper surface being the *extrados* or *back*. The *face* or *front* comprises the visible ends of the voussoirs, and is bounded by the intrados and extrados. *Abutments*, or outer supports, are distinguishable from intermediate supports, or *piers*, by their greater weight and strength. The sides of the abutments and piers are known as *jambs*, and their upper surfaces or *skewbacks* (SS in Fig. 157) radiate from the centre of the arch.

The *span* is the extreme width of the opening over which an arch is formed; the *springing line* marks the intersection of the arch with the abutments or piers, and the vertical height, from the springing line to the underside of the crown, is known as the *rise*. The *centre* is the point from which the arch is struck. Some arches are struck from two or more points. *Normals* are radiating joints drawn from the centre, perpendicularly to the curve of the arch. A *spandril* is the part of an arch contained between the extrados and a horizontal line drawn through the crown. *Haunches* are the sides of the arch from its springing line to about half-way up to the crown. *Springers* (SS, Fig. 158) are the first or lower stones placed on either side of the arch at the commencement of its curve. *Imposts* are projections (II in Fig. 158) forming the upper part of the abutments or piers. Courses parallel with the face of the arch and more or less circular in form are known as *ring courses*; those at right angles to the face are *string* courses. *Heading joints* are those between the stones of the ring courses, and *coursing joints* those between the stones of the string courses.

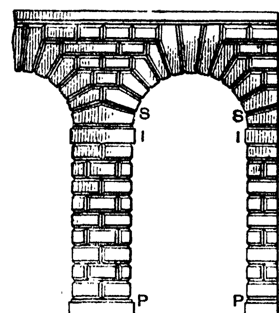


FIG. 158.

Arches of Various Forms.—Various forms of arches are illustrated in Figs. 159 to 168.

Semicircular Arch (Fig. 159).—This has its centre of curvature on the springing line, and its radius is equal to half the span.

Segmental Arch.—In the *Segmental arch* (Fig. 160) the curve of the intrados is struck from a centre below the springing line.

Semi-elliptical and Semi-oval Arches.—Arches of a *semi-elliptical* or *semi-oval* form are illustrated in Figs. 161 and 165. When struck from three centres, and therefore only approximately elliptical in shape (for no curve of a true ellipse is a portion of a circle), the arch has a crippled appearance at the junction of its small and large curves, whereas a true elliptical arch has a pleasing and undistorted appearance.

Parabolic Arch.—The *Parabolic arch* (Fig. 162) is used when the rise required exceeds the span of the arch.

Pointed Arches.—*Pointed arches*, of which there are several varieties belonging to different phases of Gothic art, are made up of circular arcs of equal radius, the intersection of which forms a pointed crown.

Equilateral Arch.—Fig. 163 illustrates the *Equilateral arch*, in which the centres used in describing the curve are at the extremities of the span.

Stilted Arch.—The sides of the *Stilted arch* (Fig. 164) are continued in vertical lines below the centre from which the curve is struck.

Skew Arch.—The *Skew* or *Oblique arch* (Figs. 165 and 166) has its axis set obliquely to its face.

Trumpet Arch.—The *Trumpet* or *Fluing arch* (Fig. 167) is one in which the opening at one end is larger than that at the other, and its interior is conical or trumpet-shaped in form.

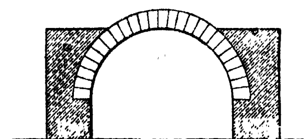


FIG. 159.
Semi-circular Arch.

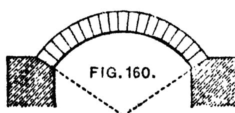


FIG. 160.
Segmental Arch.

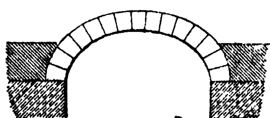


FIG. 161.
Elliptical Arch.

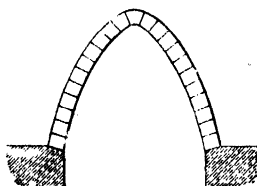


FIG. 162.
Parabolic Arch.

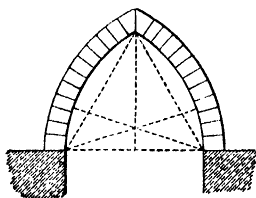


FIG. 163.
Equilateral Arch.

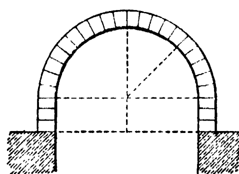


FIG. 164.
Stilted Arch.

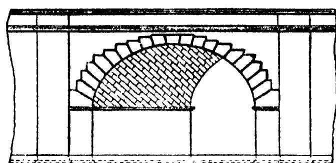


FIG. 165.
Elevation of Skew Arch.

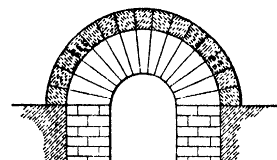


FIG. 167.
Trumpet Arch.

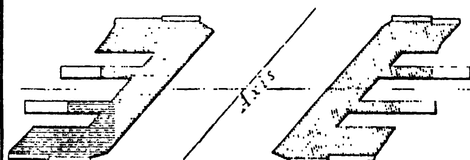


FIG. 166.
Plan of Skew Arch.

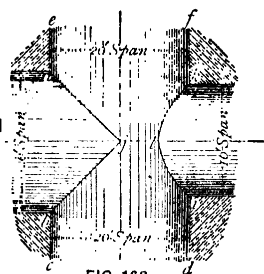


FIG. 168.
Groined Arches.
N.B. Arches all Semi-circular.

Groined Arch.—*Intersecting* or *groined* arches are shown in Fig. 168, in which a semicircular arch of 20 feet span, marked *cdef*, is intersected by one of 20 feet and one of 16 feet span respectively. The intersection, or groin, formed by the two 20-feet arches, is shown by the line *ajb*, that of the 20-feet and the 16-feet arch by the line *kli*.

Stability of Arches.—In arches of small span, such as those used in ordinary buildings, minute accuracy in the arrangement of the component parts is seldom requisite, the friction of the surfaces and the cohesion of the mortar usually being sufficient to compensate for any lack of elaborate scientific calculation. The voussoirs of arches of this description are generally of uniform height, but arches of larger span are often formed with stones of varying heights, increasing gradually from crown to skewback, as in Fig. 165, and thus preserving a uniform pressure on the voussoirs as the load becomes greater. It may be taken as a general rule that the stability of an arch of small size is assured (*a*) when the abutments of the arch are sufficiently strong to resist the thrust of the arch and to receive the superincumbent weight, and (*b*) when, in addition, the depth of the voussoirs is sufficient to enable them to withstand the pressure brought upon them, and thus to resist the tendency of the joints to open and the voussoirs to slide one upon another.

STONE ARCHES AND THEIR CONSTRUCTION

Flat Arches.—In *straight* or *flat* arches (Fig. 169) the joints radiate to a common centre *c*, found by describing an equilateral triangle upon the soffit, *ab*. The stones for this and other forms of arch are sometimes worked with rebated or stepped joints, as in Fig. 170. Another variety

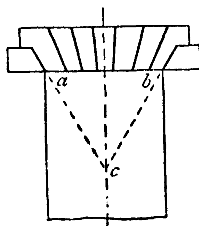


FIG. 169.

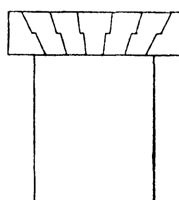


FIG. 170.

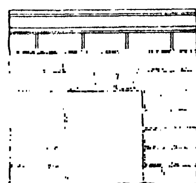


FIG. 171.

of the flat stone arch (Fig. 171) has converging joints and square skewback seatings. Flat arches are usually constructed with a rise or *camber of* about ⅛ inch to every foot of span to allow for settlement while the mortar is setting.

Tabled Cut Stone or Ashlar Arches.—The voussoirs of ashlar arches are often tabled or worked to bond in with the courses of masonry in the general walling, as shown in Fig. 158. The first proceeding is to set out a full-size drawing of the arch curve, then to divide the intrados into as many parts as there are arch stones. Lines drawn

from the centre of the arch to the extrados through the points thus determined give the various shapes and sizes of the voussoirs. From the working diagram so laid out, wood or zinc templates are prepared for the use of the stone-cutters. In setting the voussoirs the space occupied by each stone, including the thickness of the joints, is marked on the temporary wooden centre that supports the arch during its construction. The stones should be set alternately on either side of the opening in order to ensure uniformity of weight, the keystone being the last of the arch stones to be fixed. When, owing to the thickness of an arch, the distance from intrados to extrados cannot be filled by a single stone, the masonry of the soffit should be regularly bonded, the voussoirs being made of the same width throughout, but of varying lengths to ensure good work. The voussoirs of a stone arch should be carefully cut and worked so that they may bear closely and evenly against each other, and enable the jointing to be as thin as possible. Care should be taken that the joints of the stonework are of the same width throughout, otherwise the bearing will not be uniform. Wherever arches are supported by piers or columns, the springing stones must be so cut as to enable them to bond properly into the spandrils, which, as far as possible, should be free from small wedge-shaped stones. Cut stone arches in buildings are usually formed with a brick backing, and in cases where the abutments are too weak to resist the thrust of the arch, one or more steel beams may be built in the walling immediately over the opening.

Rubble Stone Arches.—Rubble stone arches are usually constructed with small stones, roughly dressed to the shape required, and laid in cement mortar.

Relieving Arches.—Relieving or discharging arches are often formed to relieve stone lintels from the weight of the wall above them. In such

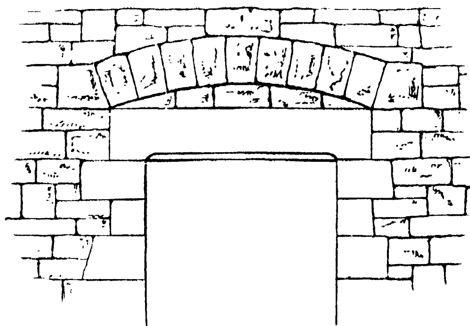


Fig. 172.—Stone Lintel with Relieving Arch.

cases it is essential that the ends of the relieving arches should be prolonged to clear the ends of the lintel, as in Fig. 172.

BRICK ARCHES

Classification.—Brick arches may be classified as follows :—(1)Rough Arches, (2) Axed Arches, (3) Gauged Arches.

Rough Brick Arches.—Rough arches are constructed with ordinary bricks that are neither cut nor otherwise accurately worked to wedge form. Consequently the joints are wider at the extrados than at the intrados, as in Fig. 173. For this reason rough brick arches of quick sweep and small span are usually formed with half-brick rings. Flat arches of larger span are often built with 9-inch rings in English, Flemish, or Heading bond. Arches $1\frac{1}{2}$ bricks thick are built

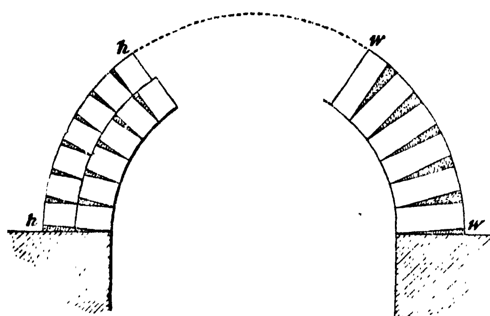


FIG. 173.—Brick Arch, showing Opening of Joints at Extrados.

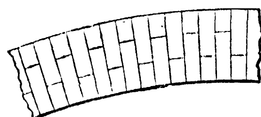


FIG. 174.

as shown in Fig. 174. In constructing arches with half-brick rings it is advisable to build the lowest ring with thin joints, and to thicken the joints progressively as the extrados is approached, an arrangement minimising the danger of fracture from unequal settlement.

Arches with Bond Blocks.—Arches are sometimes built with blocks (as BB, Fig. 175) set in cement and placed at intervals so as to form a bond throughout the entire thickness of the arch.

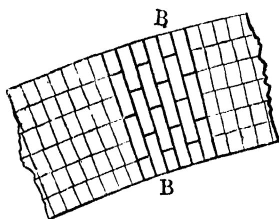


FIG. 175.

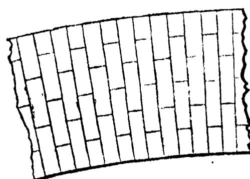


FIG. 176.

Thick Arches bonded throughout their Depth.—The joints in the extrados of the arch, shown in Fig. 176, are necessarily very wide, but the disadvantages of this structural defect may be reduced by using quick-setting cement mortar.

Relieving Arches.—Fig. 177 illustrates a rough brick relieving arch,

formed to protect a wood lintel from the weight of the wall above. The relieving arch must abut on the wall clear of the ends of the lintel, otherwise in the event of any failure of the latter the arch would loose its supports and fall in. The filling-in portion of the walling between the top of the lintel and the soffit of the relieving arch is called the *core*. A flat or slightly cambered arch, in which wooden plugs (*pp*, Fig. 178) are inserted for the attachment of the door or window frame, sometimes takes the place of the lintel.

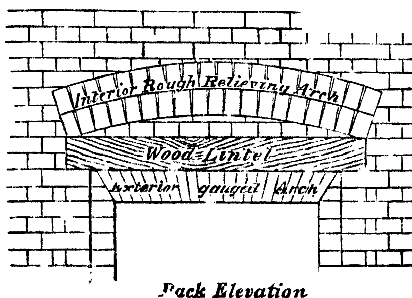


Fig. 177.—Showing Relieving Arch.

Flat Arches strengthened by Tension Bars.—Rough flat arches of wide span can be strengthened by flat steel tie bars extending along the soffit, and suspended at short intervals from rods passing through the depth of the arch, and secured at the extrados by plates and nuts.

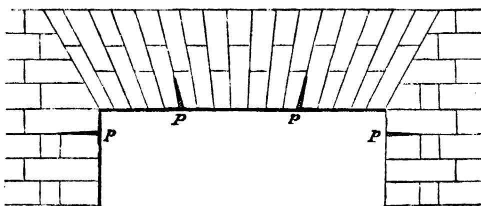


Fig. 178.—Rough axed Arch with Plugs.

French or Dutch Arches.—The structurally weak *French* or *Dutch* flat arches illustrated in Fig. 179, are occasionally used in walls intended to be finished with plaster or other outer covering. The extrados of a flat brick arch should be perfectly horizontal, but its intrados should have a camber of ⅛ inch per foot to allow for settlement. Heading joints should be horizontal throughout.

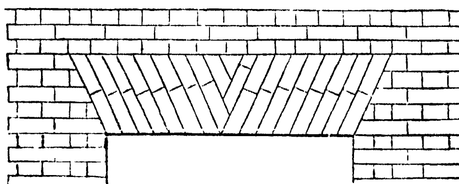


Fig. 179.—French or Dutch Arch.

Axed Brick Arches.—The bricks of axed arches are roughly cut to a wedge form. Arches of this description are chiefly used over openings, the surface of which is to be plastered or otherwise faced, but are sometimes used in *facework*.

Gauged Brick Arches.—Gauged arches are built with specially made bricks, known as *cutters* or *rubbers*, capable of being easily cut and rubbed to the requisite form. Gauged arches are chiefly used for external facework, a rough relieving arch being formed behind the face arch to support

the weight of the wall above. This inner arch usually takes the same form as the external face arch.

Straight Face Arch.—If the head of the opening is required to be flat, or nearly so, in form, a straight gauged or camber arch (Fig. 180) is used. When the wall in which the arch occurs is faced externally with bricks of a superior kind to those used for the general walling, the gauged arch extends into the wall for a thickness of only half a brick, and the inner part of the opening is spanned by a lintel, with a rough discharging arch over it.

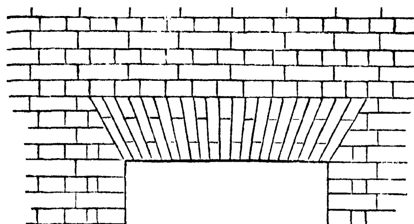


FIG. 180.—Straight Arch Window Head.

Segmental Face Arch.—A window opening with a segmental arched

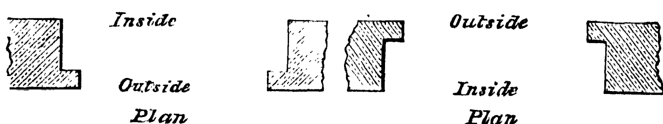


FIG. 181. FIG. 182.

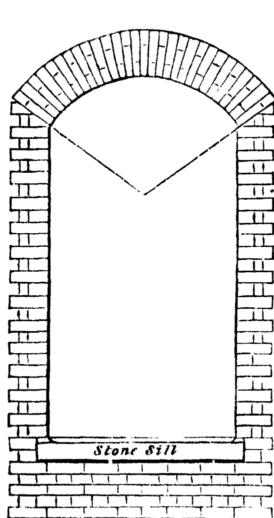


FIG. 183.

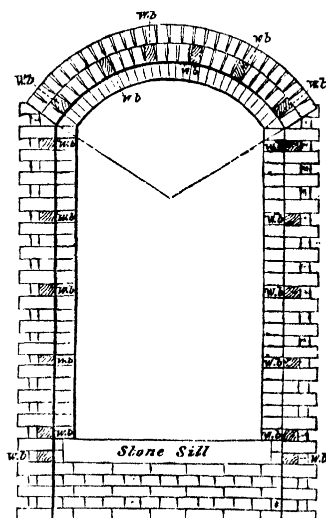


FIG. 184.

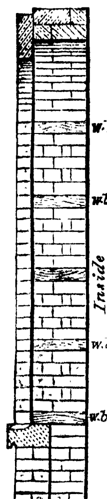


FIG. 185.

Window Opening with Segmental Arched Head.

head is shown in plan, section, and in external and internal elevation in

Figs. 181 to 185. In this example the gauged arch seen in the external elevation has a thickness equal to the depth of the reveal (in this case 4½ inches), and, as appears from the section (Fig. 185), it is unsupported by the rest of the wall. The rough brick arch in two half-brick rings containing wood bricks, *wb*, or, in good work, plugs, to secure the sash frame, is formed over the opening in the remainder of the thickness of the wall.

Semicircular Face Arches.—Semicircular brick face arches built over windows are arranged in the same manner as segmental arches.

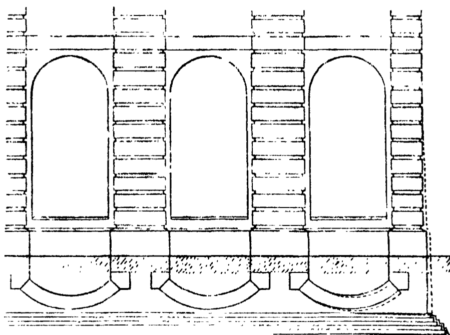


FIG. 186.

Inverted Arches.—Where the natural foundation is of a compressible nature, inverted arches are used for the purpose of uniformly distributing over the foundations the concentrated weights imposed by heavily loaded piers, as shown in Fig. 186. Inverted arches should have good abutments on each side, otherwise they are liable to thrust out the weaker portions of the walling, as shown in dotted lines.

VAULTING

Definition.—In its simplest form a vault may be described as an arched structure of stone, brick, or concrete, covering the floor space between two opposite walls or piers.

Classification.—Vaults may be classified as (*a*) Barrel or Continuous Vaults, (*b*) Groined or Intersecting Vaults, and (*c*) Groined and Ribbed Vaults.

Barrel Vaults.—Fig. 187 illustrates the cross-section of a simple barrel or cylindrical vault, resting upon two parallel walls, which must be sufficiently strong to resist the thrust of the vault. As the thrust upon the walls increases from the crown to the springing, the stones of barrel vaulting are, preferably, *decreased* in thickness as they approach the crown. But the voussoirs should always be of uniform width.

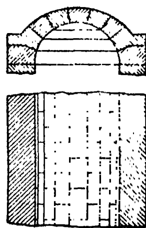


FIG. 187.

Groined Vaults.—The intrados of a groined vault is formed by the interpenetration of cylindrical surfaces intersecting each other at one common point, so that no part of the surface of one cylinder is contained between the concavity of another. As a rule the summits of the cylindrical surfaces are in the same horizontal plane, and their intersections are right lines. But this result is only obtainable when

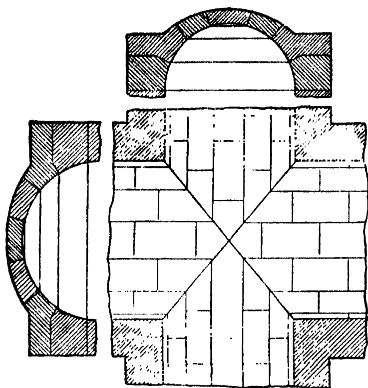


FIG. 188.

the radii of the interpenetrating vaults are equal and spring from the same level. In all other cases the plan of the intersection of the two surfaces is a curve.

In a groined vault consisting of two cylinders, the axes of the surfaces are usually at right angles to each other, and as they terminate upon walls at right angles to their axes the sides are constructed upon a rectangular plan (see Fig. 188).

Forms produced by the Intersection of Arches.—Whatever may be the form of an arch the figure produced by a plane cutting it in an

FIG. 189.

oblique direction can be determined by the method of ordinates, under which it will be seen that the curve of one arch can be developed from that of another. For example, let MFL, Fig. 189, be the section of an arch and BADC its plan, and let it be cut by a plane perpendicular to the plan and in any direction as CA. Then the form of the arch, as shown on the surface of the section, may be found thus :—

Take any number of points, as *f*, *e*, *d* in the curve, and from each point

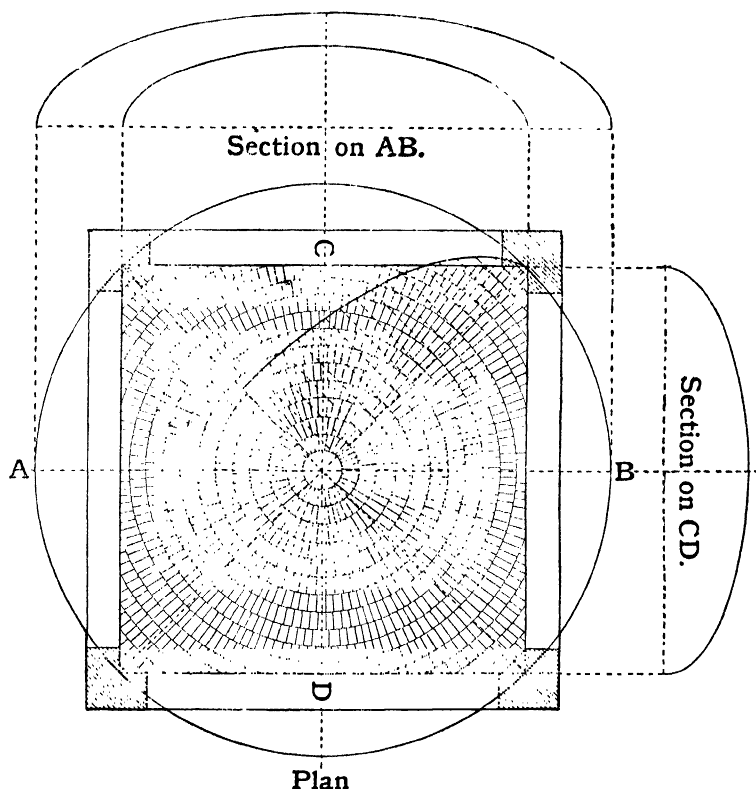


FIG. 190.

draw a line parallel to the direction of the arch to meet the line of section CA, as at the points 4, 5, 6. From each of these points raise a line perpendicular to CA, and on these perpendiculars set off, from the line CA, the height of the corresponding points in the arch above the springing line ML. For example, make EG equal to NF, 4K equal *gd*, and so on, and through the points G, K, I, H, C draw a curve, which is the form of half the arch required, and the other half will be similar.

The line of intersection of two arches, when they are formed so that the intersection is in a plane, is determined in the same manner. To make the intersection in a plane, let B D, Fig. 189, be the line of intersection, and from each of the points 1, 2, 3 in this line draw a line in the direction or parallel to the sides of each arch, and make the corresponding points *a*, *b*, *c* in these arches of the same height above their respective springing-lines. As completed, the figure shows the plan and sections of a plain groin, with the joints of the stones inserted in the plan.

Groined and Ribbed Vaults.—As the primary object of Gothic, or Pointed, vaulting was the concentration of the load upon isolated points of support, a method of construction was gradually evolved by the mediæval architects, under which the groins of the vault were marked by a series of strong arched ribs, which supported light filling-in pieces of stonework, known as panels or *severies*, and transferred the load of the vault to piers of masonry of sufficient strength to resist the thrust and weight thus thrown upon them.

Brick Vaults.—When executed in brickwork, rectangular groined vaults are necessarily weak and imperfect in construction, owing to their weakness at the groin angles, due to the necessity of cutting the bricks obliquely, and thus rendering them liable to be thrust out of place. Another method of brick vault construction, under which a cylindrical brick arch, varying from one to two bricks in breadth, is formed to follow the line of groin from pier to pier, and in which the filling-in arches are set back from the face of the groin arches, gives a far more satisfactory result. A brick vault of an entirely different type is illustrated by Fig. 190. In this example the surface of the intrados, everywhere concave from below, has a greater curvature as it recedes from the centre. The principle governing the design of this vault is that of a hemispheroid, the diameter of which is equal to the diameter of a square plan cut by four planes, each of which passes through one of the sides of the square perpendicularly to the plane of the circle. Under this system of brick vaulting the courses of brickwork form a series of concentric circles, the diameters of which increase as they recede from the centre.

DOMES

Definition.—Convex roofs or vaults, usually either spherical, elliptical, polygonal or conical in form, and constructed to cover circular, elliptical, polygonal or rectangular floor areas, are known as *domes*.

In its most simple form a dome is circular in plan, the circle being the most perfect figure for the purpose, although squares and regular polygons often form the basis of dome construction.

Pendentive.—When, as in Fig. 191, a spherical dome is intersected by vertical planes or arches equidistant from its centre, corbellings resting on the internal angles of the supporting piers are introduced to carry the upper part of the dome immediately above them. The spandril

supports thus formed between the boundaries of the planes are called *pendentives* (PP, Fig. 191), and by their use the upper part of a dome, rising from a polygonal or square plan, can be developed into a structure of circular form.

Drum.—In order to obtain greater height the upper part of a dome is sometimes raised upon a circular wall placed above the pendentives and known as the *drum* of the dome.

Construction of Domes.—The construction of a dome is less difficult than that of an arch, because the tendency to fall shown by any part of the structure is not only counteracted by the pressure of the parts below but also by the resistance offered by those on each side. And it is for this reason that a dome may be safely left open at the top without a crowning keystone.

Stability of Domes.—In domes, as in arches, the resultant of the pressure of any point, known as the *curve of equilibrium*, must fall within the thickness of the dome or its supports in order to provide for the stability of the structure.

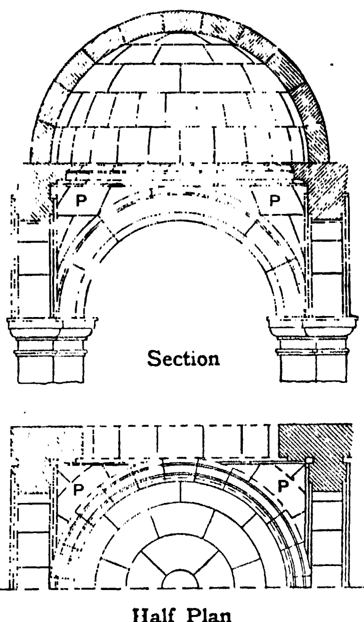


FIG. 191.

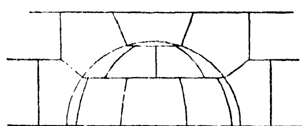
Stone.—The masonry of domes differs from that of arches inasmuch as every stone or voussoir is shaped to fill part of the void in a sphere and not in that of a cylinder. Stone domes are built in horizontal courses, each of which possesses arch-like properties, but when a spherical dome of this description, and rising to a considerable height, is constructed with masonry of uniform thickness from springing to crown, its tendency will be to thrust out the lower courses of the structure. In such cases the dome should be secured, and its stability assured, by building in a stout metal encircling band at a height of about $\frac{1}{4}$ of the whole diameter of the dome.

It may be assumed, as a general rule, that the horizontal thrust of a dome will be wholly counteracted by a resistance to tension in the circle equivalent to $\frac{1}{6}$ of the horizontal thrust. When this strain is provided for either by the strength of the walls at the springing of the dome, or by metal reinforcement, the structure will be secure at whatever height from the ground it may spring, provided the vertical walls or piers are sufficiently strong to withstand the weight placed upon them. In this connexion it may be stated that more often than not it has been owing to the inadequate strength and inequality of settlement of the supporting

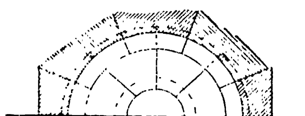
walls or piers that so many well-known domes of great architeetural interest, having shown signs of failure and weakness, have had to be strengthened.

Joints.—The joints of a spherical stone vault or dome are of two kinds, the horizontal joints being portions of conic surfaces, while the vertical joints are formed in surfaces tending towards the centre of the dome (see Fig. 191).

Stone Niches.—A niche is a recess formed in the wall of a building, and usually intended for the reception of statuary. The surfaces of niches are generally concave in form, the back of the shaft being cylindrical and the canopy or head spherical in shape. Fig. 192 shows the plan and elevation of a spherical niche formed in a straight wall, and con-

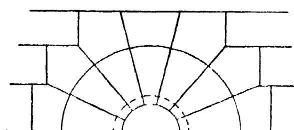


Elevation



Plan

FIG. 192.



Elevation



Plan

FIG. 193.

structed with horizontal splay beds and vertical joints. A similar stone niche in which the joints of the masonry radiate from the centre is illustrated in Fig. 193.

Brick Domes and Niches.—Small brick domes and spherical niches are constructed in the same manner as stone domes and niches. A niche, which may be regarded as a portion of a dome (usually half a dome), is illustrated in Fig. 194. The construction of a brick niche is one of considerable difficulty on account of the very thin size to which the radiating bricks have to be reduced at the inner circle. Within that circle the bricks must be so laid that their longest dimensions are horizontal and parallel to the plane of the front from which the niche recedes. In Fig. 194, (*a*) shows the elevation of the niche, (*b*) and (*c*) the plans of alternate courses of brickwork, and (*d*) is a vertical section taken through the centre of the head.

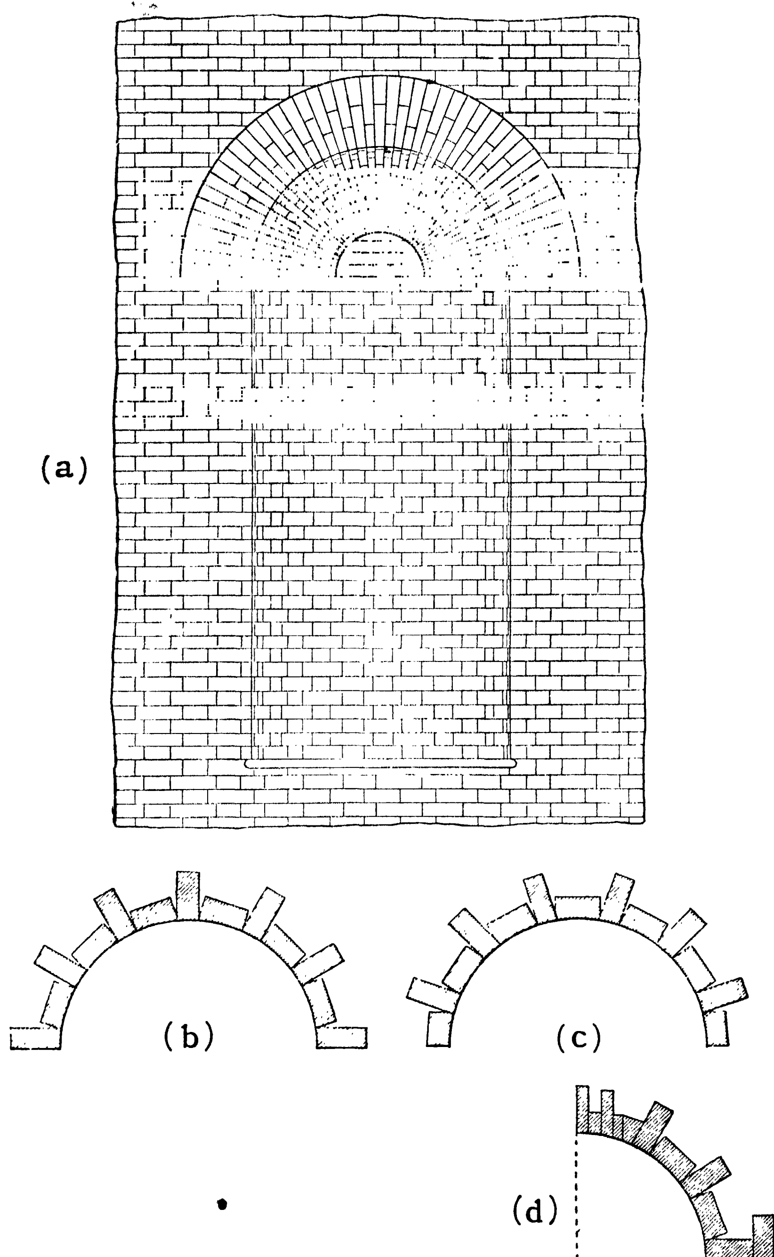


FIG. 194.

CHAPTER X

CHIMNEYS, AND SETTING FOR STOVES, RANGES, AND BOILERS

By William Pywell, F.R.I.B.A.

CHIMNEYS

Technical Terms.—This section is not intended as a complete glossary, but merely as a short collection of definitions explaining the meaning of the technical terms most frequently employed in connexion with chimney, flue, and similar work.

Batter.—To incline from the perpendicular; to taper.

Camber.—To curve in the form of a segmental arch.

Caulk.—To turn up and down the end of a bar to prevent it being drawn out of a wall.

Cheeks.—The upright splayed sides of a fireplace opening made of iron, stone, brick, or tile.

Corbel.—A horizontal course of brick or stone projecting beyond a similar course below. Corbels are often formed by two or more courses, each projecting beyond the course below.

Coving.—A lining of metal or tiles around the opening above the hot-plate of a kitchener.

Chimney-back.—The part of the wall which forms the back of a fireplace.

Chimney-breast.—The part of the wall facing a room, and containing the chimney flues.

Chimney-jambs.—The vertical sides of a fireplace opening.

Chimney-piece.—The architectural dressings around a fireplace.

Chimney-shaft.—The part of the chimney which rises above the roof of a house, or from the ground or boiler-house in the case of an isolated chimney.

Chimney-stack.—Several flues collected into one group.

Flaunching.—The weathering to the top of a chimney, usually of cement and tiles or slates.

Gathering.—The upper part of a fireplace which contracts, as it ascends, to the size of a flue.

Parget.—To render the inside of a flue with lime-and-hair mortar, frequently with an admixture of cow-dung.

Party-wall.—A wall between two houses, in which each has an equal interest.

Pocket.—A vacant space.

Register.—A metal door or damper to close over a fireplace, so called because it was originally a registered or patented contrivance.

Rendering.—Laying on a coat of plaster on brick or stonework, or the coat of plaster so laid on.

Template.—A piece of stone under the end of a girder to distribute the weight over several joints of brickwork.

Throat.—The part of a fireplace between the gathering and the flue.

Weathering.—The slope given to an approximately horizontal surface to enable it to throw off rain.

Withe.—The partition between two flues in the same stack.

Fire Precautions.—Security against the spread of fire to other parts of a building is a very important consideration in the construction of flues and fireplaces.

No set-off or other lodgment for soot should be made in any flue. Nothing of an inflammable nature must be fixed within 9 inches of a flue, and there should be an air space of 2 inches between brickwork and timber. No wood plugs should be driven into the brickwork within 9 inches of a flue, and no wood fixings should be within 6 inches of the hearth surface. Iron holdfasts or metal fastenings must not be fixed within 2 inches of any flue. Hearths must, of course, be of incombustible material, and laid on brick trimmer arches, rough stone, or concrete slabs. The back hearth must be bedded on solid brickwork, and no timber or other woodwork inserted beneath. The front hearth should extend 9 inches on either side of the opening, and project 18 inches in front of the brick chimney jambs.

Facilities for the easy and effective cleaning of chimneys and flues should always be provided by the introduction of soot doors wherever requisite.

Brickwork of Flues and Chimneys.—The brickwork of all flues must be properly bonded, and the joints well flushed with mortar, and brickwork 9 inches thick should enclose the flues.

Chimney breasts and stacks containing flues should be rendered in cement where they pass through floors and roof spaces.

DOMESTIC CHIMNEYS

Fireplaces.—A fireplace is formed by building out jambs from the walls, or by a projection on the back of the wall, and turning an arch over the opening, upon which is erected the chimney breast to contain the flue.

Construction and Support.—The jambs or projection should be carefully built upon solid foundations. Where economy is not very pressing the jambs should be 14 inches wide, but jambs 9 inches wide may be used without contravening the Model Byelaws of the Local Government Board.

Where a fireplace is required on an upper floor without support from a fireplace or piers below, the jambs are corbelled out from the wall and built upon York stone templates. The corbelling must be gradual,

properly bonded to, and not exceed the thickness of, the wall below. Fireplaces, in a house of more than one story, usually stand one over the other, the flues from the lower rooms being carried to one side or the other, in the jambs of the fireplaces above. The fireplace arches are turned in 9-inch brickwork, in cement mortar, on 2½ inches by ⅜-inch or 3 inches by ½-inch wrought-iron cambered chimney bars, with ends caulked and built 9 inches into the jambs, if the breast project more than 4½ inches and the jambs be less than 13½ inches wide.

Size of Opening for Ordinary Grates.—The size of the opening varies according to the grate to be used. The depth should not be less than 14 inches, and need not be more than 18 inches for ordinary grates and interiors. The widths of fireplace openings vary from 18 to 27 inches for small rooms, to 42 inches and upwards for large rooms. The height of a fireplace opening should be 3 feet 3 inches for ordinary grates.

Size of Opening for Kitcheners.—Kitcheners require a minimum depth of 22½ inches, which, with mantel jambs, only allows for brick on edge at the back of the covings, and flues 3 inches deep. The depth of a kitchener opening should be 27 inches, and the back should be 9 inches thick. The breast above the mantel-shelf may be set back sufficiently to contain the flue, and thus economise brickwork. The height of the opening should be 5 feet for kitcheners with covings.

Smoke Prevention.—It is a common practice to form the throat of a chimney by gathering over the brickwork at the back of the fireplace arch until the opening is reduced to the required dimensions of the flue. Smoky chimneys may usually be traced to the gathering over, and the formation of *pockets* for the eddying currents of cold air, which prevent the heated air and smoke from ascending the flue (see Fig. 195). This fault may frequently be corrected by building up the *filling* on either side of the stove with solid work, as in Fig. 196, thus abolishing the *pockets*. The flue, of its proper size, should be formed immediately at the back of the fireplace arch, and directly over the fire. After ascending vertically for a short distance it may then be gathered to the right or left to take its place in the group of flues. The grouping of flues in a stack is economical and conduces to efficiency.

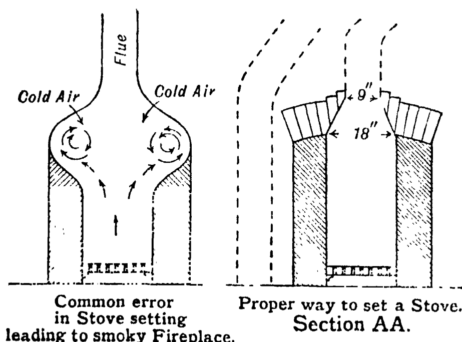


FIG. 195.

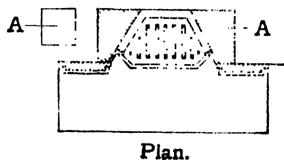


FIG. 196.

In gathering over the flues the off-sets are cut on the splay to suit the curves required, and are rendered or pargetted as the work proceeds.

Every fireplace must have a distinct flue to itself, and no openings for ventilation or other purposes should be made into a smoke flue. Flues must be carried well above the roofs of adjacent buildings, otherwise the wind will beat down the ascending air in the flues, and cause smoke to enter the building.

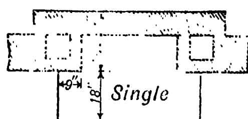


FIG. 197.

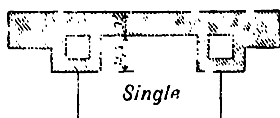


FIG. 198.

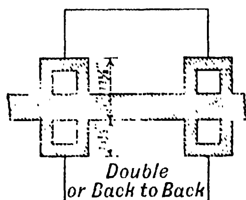


FIG. 199.

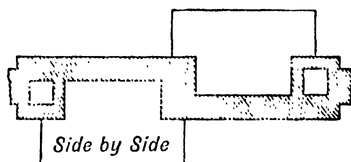


FIG. 200.

Arrangement of Fireplaces.—Fireplaces may be arranged with the projection exterior to, or into, the room, as in Figs. 197 and 198; back to back, as in Fig. 199; side by side, as in Fig. 200; or one or other combination of the quadruple angle fireplaces shown in Fig. 201, may be adopted.

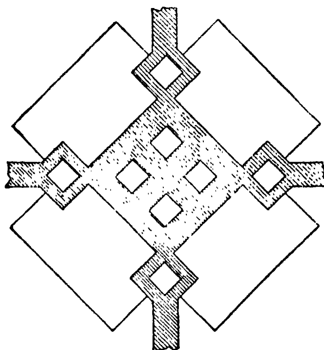


FIG. 201.

Where fireplaces are on a party-wall they must have 9-inch backs to a height of at least 6 feet, and where they are placed on external, or other walls, the backs may be 4½ inches thick, but must be rendered in cement, to comply with Byelaws sanctioned by the Local Government Board.

As far as practicable, fireplaces should be placed on internal walls, so as to give the building the benefit of the heat radiating from the flues, and to minimise the loss of heat. Where fireplaces are built on external walls, 9-inch enclosing walls to the flues are the more necessary.

Fireplaces should not be constructed near to doors and principal windows, as when so situated the air supply to them is keener, and draughts are more apparent than if the currents of air are broken or dissipated by travelling a distance across the room.

Flues.—A flue is a duct for the conveyance of smoke, heat, or gases, and may be either (*a*) the passage, or one of the passages, for smoke in a chimney, or (*b*) a side passage leading from a fireplace to the chimney.

Flues may be classified as vertical, horizontal, and raking, but two or all three varieties may be embodied in one flue.

Vertical Flues.—These are the most common, and are built over fireplaces singly, or one above the other, and may be arranged as most convenient for the chimney stack.

Horizontal Flues.—Horizontal flues are used to convey smoke from closed stoves (Figs. 202 and 203) in the centre of rooms to vertical flues in the side walls. If below ground level the flue may have brick sides covered with fire tiles, as in Fig. 204, and if under a suspended floor the

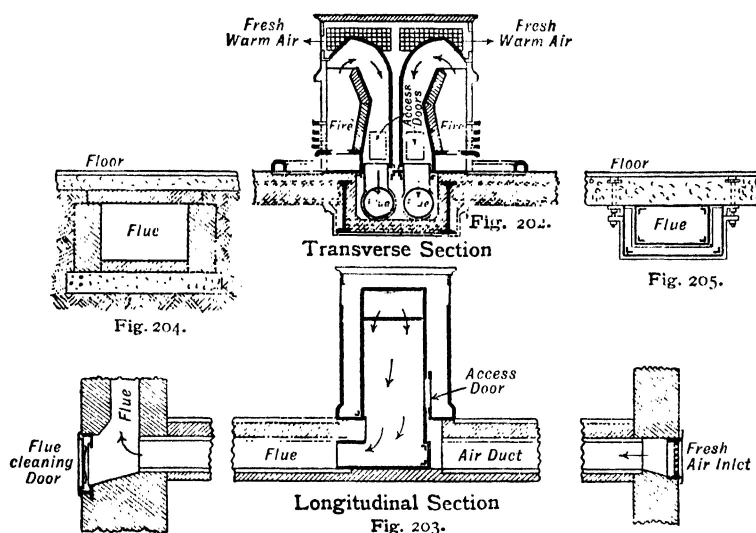


Fig. 202.
Transverse Section

Fig. 204.

Fig. 205.

Longitudinal Section
Fig. 203.

flue may be formed of 10-gauge sheet-iron, with an air jacket, and fixed as in Fig. 205, and fitted with a cleaning door in the end (Fig. 203), or the flue may be of 9-inch fireclay socketed pipes embedded in concrete on 2-inch T-bars, as in Fig. 202. Double-fire stoves require a separate flue for each fire. Access doors for cleaning the flues must be provided. Horizontal flues are largely used for hospital-ward stoves. Fresh air may be brought to a stove of this kind by a duct, as shown in Fig. 203.

Raking Flues.—A *raking flue* may be carried on an arch of any convenient shape. The arch should be in two half-brick rings. A flue may change its direction by gradual curves and inclinations at an angle of not less than 45 degrees, otherwise soot will accumulate.

Arrangement of Flues.—In the case of semi-detached or terrace houses the common practice is to build the fireplaces back to back, and the flues are brought together into a stack. This method is economical, and also tends to maintain the temperature of the flues.

Figs. 206 and 207 are respectively longitudinal and transverse sections of the flues and fireplaces between two five-storied buildings. The dotted lines in Fig. 207 show the direction of the flues on the other side of the party-wall. Figs. 208 to 213 are plans of the fireplace openings and flues at the level of each floor. The weight of the chimney breasts should

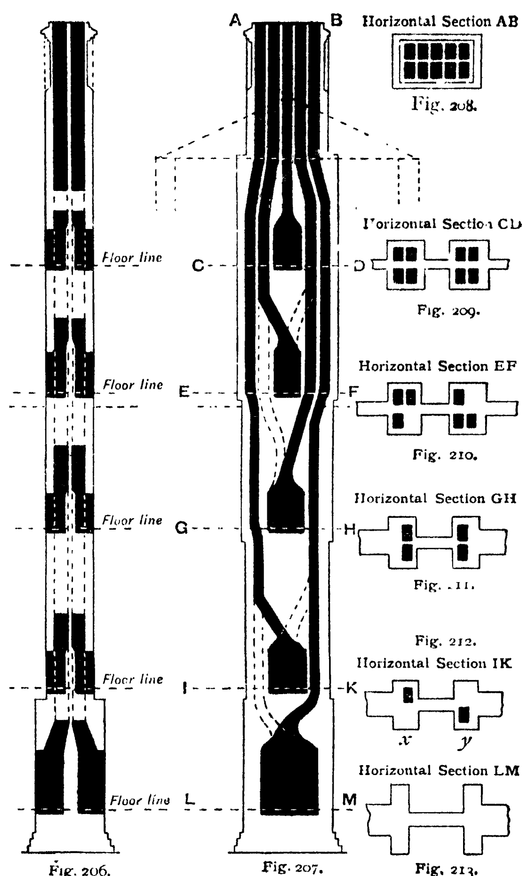


Fig. 206. Fig. 207. Fig. 208. Fig. 209. Fig. 210. Fig. 211. Fig. 212. Fig. 213.

be distributed by footings, as shown in Figs. 206 and 207, or by an invert arch between the chimney jambs under the fireplace.

In order to economise brickwork and interior space, the chimney breast in each room is generally made of minimum width, but economy of the kind must not be carried to the point of danger. For instance, to corbel out 9 inches in the thickness of a floor, as in Fig. 214, would be bad for the flue, and dangerous, as the ignition of soot on the set-off might heat the brickwork so as to set fire to the floor and skirting.

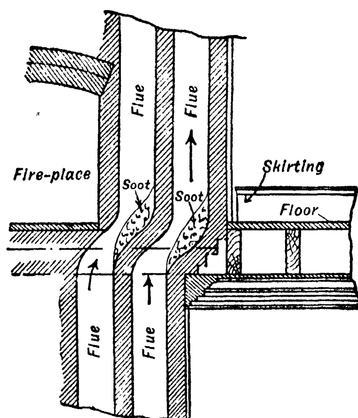


FIG. 214.—Dangerous Flue Corbelling.

In Fig. 207 it will be seen that the chimney breasts at IK are made narrower than those above, because they contain fewer flues. At GH the breast is widened to prepare for the safe passage of the flues through the floor above at EF, and to avoid the dangerous construction shown in Fig. 214. Fig. 215 shows the collection of flues from opposite sides of a house into a central stack. The flues from rooms A, B, C, and E converge towards a central stack, the space between the chimney breasts of the upper rooms being bridged by an arch, W. The brickwork forming the upper wall of the flue is raked

FIG. 215—Collection of Flues into a Central Stack.

back as shown, leaving a thickness of 9 inches above the flues for safety. As the chimney jambs of room C cannot be carried down to the foundation, they are supported by corbelling, as shown in dotted lines. The chimney breast of room A is nearer the outer wall than that of room B, in order that the fireplace may be centrally placed. To avoid widening the chimney breast below, the upper chimney jamb, *p*, is supported by corbelling in the thickness of the floor, as dotted.

It will be seen that the flue from room E, instead of having a chimney built up from the outer wall, is carried over an arch covering the recess between the chimney breast and the outer wall of room C. A soot door of not less than 40 square inches area must be fixed at S, so that the flue may be properly swept, to comply with the London Building Act.

Size of Flues.—A flue should neither be larger nor smaller than is necessary for conveying the required volume of smoke and heated air. Generally speaking, a flue 9 inches square is sufficient for very small grates, a flue measuring 14 inches by 9 inches will suffice for an ordinary fireplace, and a flue 14 inches square for a large kitchen range.

Lining and Pargetting.—The object of lining or pargetting flues is to provide against the chance of bad joints in brickwork, with the attendant fault of cooling the flue by drawing in cold air, and the danger of setting fire to adjoining woodwork. The cheapest method is to parget the flues with lime-and-hair mortar, which is greatly improved by a liberal admixture of cow-dung. This forms a tough lining, and is not so liable to crack as ordinary mortar. The best method is to line the flues with fire-clay pipes of either round or square section. Such pipes are sometimes used with air flues in combination for ventilation. Flue pipes afford great protection to flues enclosed by thin external walls, offer little resistance to the smoke, do not collect the soot, and permit the flues to be kept of uniform cross-section throughout.

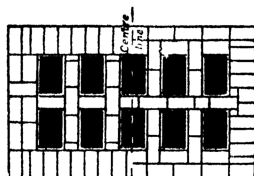
Flues are sometimes rendered with Portland cement, but such rendering should be well away from great heat, otherwise the cement will disintegrate and fall away. It may be more safely employed for the flues at the top exposed portions of a chimney stack.

Coring.—While a chimney flue is being built, it is advisable to keep within it a core of rags, straw, or shavings, in order to prevent mortar from falling upon the sides and inaccessible turns, to say nothing of a brick falling down and being forgotten. After the flue is finished, a similar core, or a brush, should be passed through to clear away any accumulation of brick cuttings and mortar, and to detect any other obstructions.

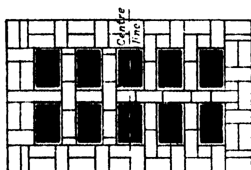
House Chimney Shafts and Stacks.—Chimneys above roofs should be built in cement, and carried at least 3 feet above adjacent ridges. They should be built of the same materials as the walls, and it is desirable to line them with flue pipes, more particularly in stone-built stacks. The outside walls of a chimney stack are often reduced to 4½ inches thick when they have passed through the roof, thus sacrificing efficiency. It is better to keep the external walls of the stack 9 inches thick throughout.

Bond.—Chimneys with one-brick external walls in English and

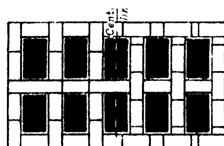
Flemish bonds are shown in Figs. 216 to 218. Where half-brick enclosing walls are used it is important that they be built in cement, as, owing to their exposed position, joints in ordinary mortar are soon destroyed by the action of the weather, thus affecting the pargetting, causing it to disintegrate and fall down the chimney. The external walls are best built in Flemish bond, because there are fewer snapped headers than in English bond, and the legitimate headers bond well with the withes, dividing the flues as shown in Fig. 217.



Half-Plans of Alternate Courses English Bond, 1 Brick Walls Fig. 216.



Half-Plans of Alternate Courses Flemish Bond, 1 Brick Walls Fig. 217.



Half-Plans of Alternate Courses Flemish Bond, Half-Brick Walls Fig. 218.

Stretching bond is sometimes used for half-brick external walls, but it leaves the cross withes quite detached from the side walls, or by intricate cutting, which is rarely done properly, the withes are either mitred or they rest 2¼ inches on the outside wall in alternate courses. This system of bond is not recommended.

Stone Chimneys.—Chimney breasts in stone buildings are generally built with bricks, which are better adapted than stone for forming the thin withes and walls required, and are less expensive than stone. Chimneys in stone are built similarly to brick chimneys. If built with rubble walling they usually have quoins, but are more frequently built in ashlar, especially the shaft between the base and cap.

Chimney Pots and Terminals.—Chimney pots are frequently placed over flues to give a *knife-edge* to the orifice, and to obviate the eddy of wind that would be caused by a flat surface at the top of the chimney beating down the smoke at its point of exit. Otherwise, if the chimney is properly built, there should be no need of a chimney pot to make it "go."

Chimney terminals, or wind guards, of semicircular or otherwise shaped flat slabs of stone or terra-cotta, are sometimes set in the flaunching to prevent down draughts, and to protect each flue from the action of those adjacent.

STOVE, RANGE, AND BOILER SETTING

Stoves.—All fire stoves should be set, or built in, solidly at the back and sides. Stock bricks in lime mortar answer well if not in actual contact with fire.

Care must be taken not to leave *pockets* on either side of the *gathering-in*, and the brickwork should be continued well up into the throat of the flue (see Figs. 195 and 196).

If a new stove is required in an old opening, everything, including the chimneypiece, should be removed, and the stove built in afresh. The

small saving of cost that might be effected by making the old filling-in do, is not worth consideration in view of the risk involved.

Ranges and Coppers.—In setting kitchen ranges and coppers, fire-bricks in fireclay mortar should be used for all positions where fire comes

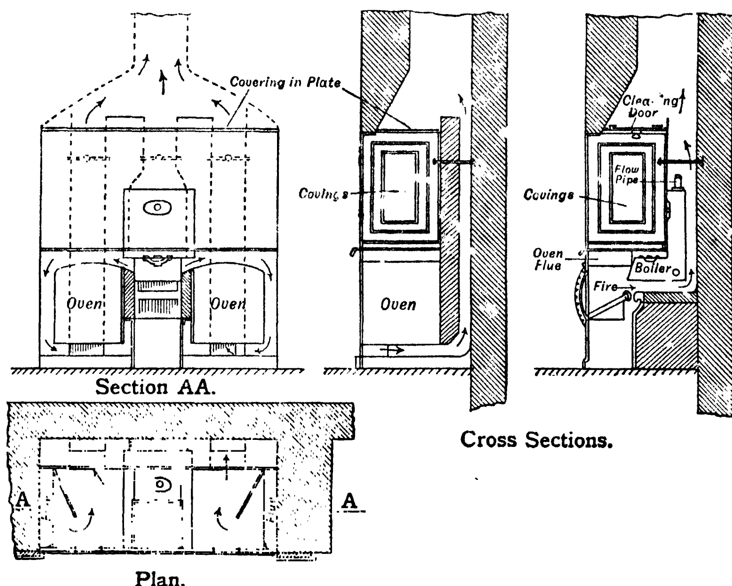


FIG. 219.—Setting of Kitchen Range.

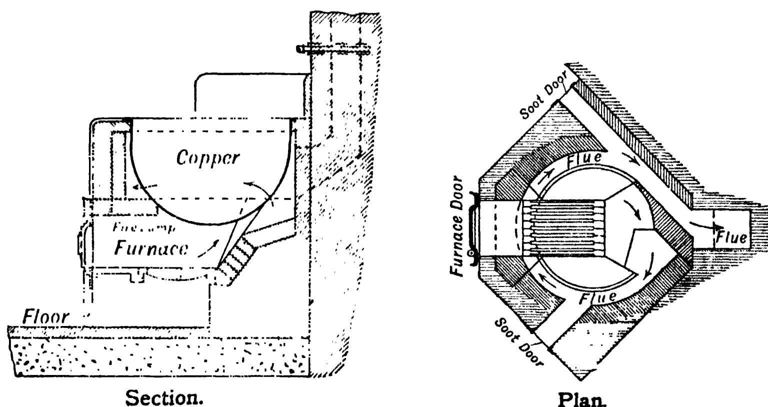


FIG. 220.—Setting of Copper.

in contact with the setting, and where there may be exceptional heat. Fireclay mortar may be composed of 3 parts of fireclay to 1 part of plaster

of Paris, mixed with water to the usual consistency. The setting of a kitchen range is shown in Fig. 219.

Coppers are set in 9-inch enclosing walls, with firebrick-lined sides to the flues in fireclay mortar (see Fig. 220). The walls may or may not have footings, but should be built on a bed of concrete from 9 to 12 inches thick. The outside and top are usually rendered in cement mortar 1 inch thick, trowel faced, and the walls above should be similarly rendered or lined with tiles in the vicinity of the copper to protect them against splashing.

Hot Water and Steam Boilers.—One of the chief points to bear in mind in setting boilers of every description is to expose as much of the heating

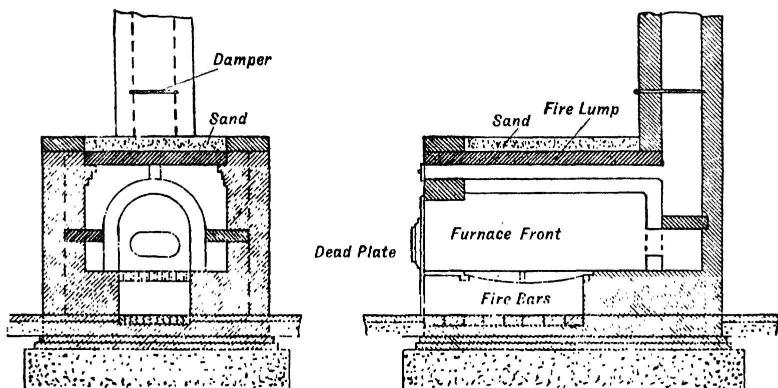


FIG. 221.—Setting of Saddle Boiler.

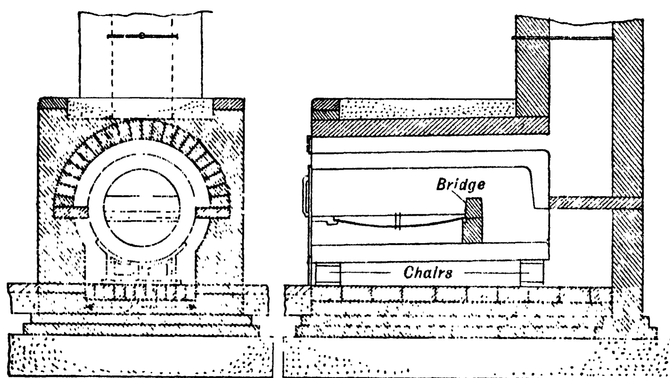


FIG. 222.—Setting of Trentham Boiler.

surface to the flues as possible. This not only makes for efficiency but saves corrosion of the boiler, as all parts in contact with brickwork are

more liable to rust than exposed surfaces. Since the introduction of sectional hot-water boilers, which require no brickwork, the use of saddle boilers, and the many variations of that type, has considerably diminished. Where large volumes of water have to be heated for baths and hot-water services generally, the Cornish Trentham boiler still holds its own. The flues around boilers should be lined with firebricks laid in fireclay mortar, and the flues made as narrow as is consistent with the size of the boiler, so that the heat may be brought to impinge on the underside and vertical sides of the boiler.

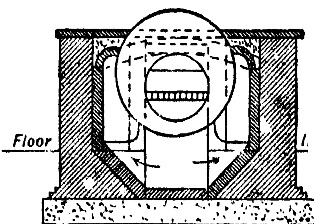


FIG. 223.—Setting of Cornish Boiler.

Fig. 221 shows the setting of a saddle boiler, and Fig. 222 the setting of a Trentham boiler, each boiler having a waterway end.

Figs. 223 and 224 represent the setting of a small Cornish steam boiler.

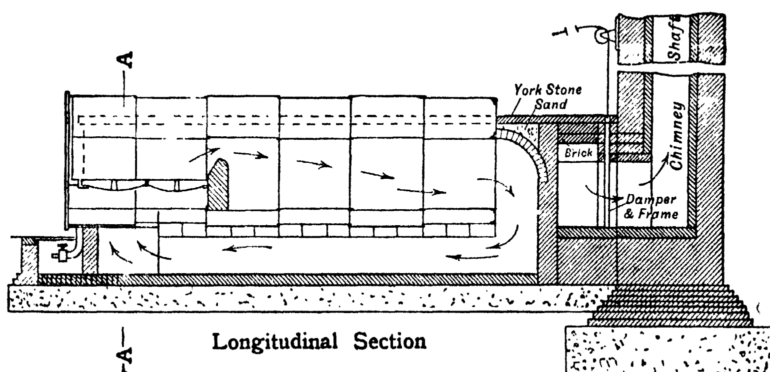


FIG. 224.—Setting of Cornish Boiler.

A Lancashire boiler differs from the Cornish type in the respect that it has two internal flues, and is set in a similar manner.

These boilers rest upon fireclay seating blocks, set upon firebrick-lined walls, and the side flues are covered in with fireclay flue-covers of an arched shape, resting upon the firebrick lining of the enclosing walls. The flue covers are made in 6-inch and 8-inch quadrant blocks 12 inches long; and the seating blocks are made with both straight and curved sides for the side flues, and of varying sizes, but usually either 9 or 12 inches long.

Care should be taken that provision is made for getting large boilers in and out of the building.

CHAPTER XI

DAMP- AND SOUND-RESISTING CONSTRUCTION—PREVENTION OF DRY-ROT

By W. Noble Twelvetrees, M.I.Mech.E., M.Soc.Ing.Civ.

DAMP-RESISTING CONSTRUCTION

General Considerations.—In addition to the importance of dryness in buildings for hygienic considerations, it is necessary that moisture should be avoided for structural reasons. Dampness in brickwork and masonry is readily communicated to woodwork, tending to cause decay throughout the structure, while the presence of moisture retards the setting of ordinary mortar, damages plastering and decorative work, and renders brickwork liable to injury by frost. While moisture rising from damp earth or due to the fall of rain or snow can be excluded by properly constructed damp courses and other familiar means, the moisture originally contained in structural materials or afterwards absorbed by them from the atmosphere, or elsewhere, cannot be dealt with so readily.

As all materials are porous in varying degree, they are penetrable by liquids and gases, or by gases alone, the gases being condensed under favouring thermal conditions. The soil upon which buildings are founded, being permeated with water and air in measure varying with local conditions, disengages gases which are absorbed by the atmosphere and building materials, while water is drawn up into the latter by capillary attraction.

Data as to the quantity of water capable of being absorbed by different structural materials are given in Part III., but it should be remembered that data of the kind do not indicate the absorption that may be expected in actual practice as the result of capillary and hygroscopic action.

Experience shows that the percentage of moisture absorbed from the air and by capillary attraction from the soil may in some cases approach within measurable distance of the proportion due to direct immersion in water. Further, it should be noted that a wall is more receptive of moisture if the materials are already humidified by vapour, permeated by earthy salts, or covered by efflorescence, and that air and other gases filling voids in a wall continue to absorb moisture at any height and at all temperatures until the dew-point is reached.

Sources of Moisture in Buildings.—In practice, moisture in buildings is derived from one or more of the four different sources classified and briefly discussed in the following notes.

Water of Construction.—This consists of moisture in the materials when delivered, absorbed during exposure on the site, or added to them for structural purposes. As a general rule, such moisture may be regarded as being of temporary character, and capable of being removed by evaporation within reasonable limits of time.

Water of Capillarity.—This is always more or less evident, being drawn up from the soil by capillary action, unless intercepted by an impenetrable barrier. The interposition of an efficient damp course between the soil and the foundations, or between the latter and the superstructure, is the best means of protection against water of capillarity. In cases where the structure is in contact with the soil above foundation level, a vertical damp course is necessary.

Water of Condensation.—Resulting from the condensation of vapour from the air, either in the pores of structural materials or upon their outer surface, water of condensation is sometimes a source of considerable trouble. It is less evident in buildings where the construction is homogeneous throughout, or formed of materials whose physical properties are approximately equivalent, than in buildings embodying hard and dense materials in contact with others of soft and porous character. If the atmospheric conditions are such as to encourage the formation of water of condensation to an important extent, moisture may tend to accumulate in the interior of walls, however carefully they may be protected by horizontal and vertical damp courses, and other impervious linings on part of the exterior or interior surface. Cases have been known where the moisture so accumulating has broken out anew above the protective sheathing. To action of the kind may often be attributed the cracking, buckling, and detachment of stucco on brickwork, and the failure of other protective coatings.

Water of Infiltration.—This is represented by moisture due to defects in roof coverings and other structural details, flooding in times of heavy rain, burst water-pipes, and other causes. Protection against the absorption and infiltration of water from the outside can be afforded without difficulty by judicious design, sound construction, and efficient maintenance.

DAMP-PREVENTION METHODS

In the following notes, we discuss briefly the various methods available for the prevention and removal of moisture from buildings.

Impervious Foundation Raft.—Concrete or reinforced concrete foundation rafts (see Chapter II.), with or without a continuous layer of asphalt, are most effective in preventing damp and bad air from rising out of the ground into the building. The Model Byelaws of the Local Government Board provide for a layer of well-rammed concrete, at least 6 inches thick, to be formed over the site to seal the ground air.

Horizontal Damp Courses.—In most cities and towns the local byelaws make compulsory the provision of a proper damp course. Even in places where this precaution is not required by building regulations it should never be omitted.

Slate.—In forming a damp course with slates, these should be thick, laid to break joint properly, and bedded in cement mortar. In case of unequal settlement, a slate damp course may develop cracks, permitting the passage of water by capillary action.

Blue Brick.—This material does not make a reliable damp course, as even the best Staffordshire blue bricks are permeable by moisture, to say nothing of the risk presented by the possibility of broken joints.

Glazed Stoneware.—Perforated slabs of glazed stoneware, made to the width of the wall, make a good damp course, and are useful for the ventilation of spaces under the flooring, but as numerous joints necessarily exist between the slabs, it is impossible to guarantee that moisture will not be drawn up by capillary attraction.

Sheet Lead.—Being costly and apt to be squeezed out under heavy loads, lead is rarely used for damp-course construction in the present day.

Asphalt.—This material forms an admirable damp course, being easily laid, elastic, capable of withstanding heavy pressure, and perfectly continuous. The damp course can be spread on the site, or may consist of prepared bituminous sheeting, made specially for the purpose. Where the latter variety is used, care must be taken to make a jointless continuous course.

Bituminous Felt.—Materials coming under this general head should not be employed unless evidence is forthcoming to prove that they are both durable and absolutely impervious to moisture.

Vertical Damp Course.—In addition to the customary precautions against the rise of moisture from the earth, walls in contact with the soil, or exposed to heavy rains, require protection by a vertical damp course or by other means.

For instance, the walls of a basement or cellar should have a vertical damp course, preferably of asphalt, continuous with the horizontal damp course, and extending to a little above ground-level; if the floor is not constructed of thoroughly impervious material, it should be made damp-proof by a continuous layer of asphalt, either in the substance or upon the upper surface of the floor. The Model Byelaws of the Local Government Board provide that any part of a new building below ground-level and in contact with the earth shall be built with double walls, having an intervening cavity of a width of 2½ inches, and extending to a height of 6 inches above ground-level.

Air drains, or *dry areas*, are narrow areas, 9 to 12 inches wide, formed around such parts of the walls of a building as are below ground-level, their object being similar to that of cavity walls.

In the case of walls above ground-level, which by reason of the porous nature of the materials, or of exceptional exposure to rain, require external protection against the penetration of moisture, the exterior may be rendered with cement mortar, covered with slates or tiles, or painted with tar, pitch, or some special damp-proofing composition.

Removal of Dampness from Existing Buildings.—An ingenious system for the removal of moisture from existing buildings, and for the prevention of dampness in buildings generally, is that devised by Mr. A. Knapen, M.Soc.Ing.Civ., a Belgian architect and civil engineer. Briefly

described, the system is one inducing the penetration of air to the interior of walls by means of tubes made of porous material, and inserted into the walls, either at the time of building or afterwards. The tubes are closed at the inner end, and are inclined downwards towards the exterior. If the wall is of the same kind of material throughout, the tubes extend approximately to the centre line, and if it is formed of two kinds of material the tubes are taken to the line of division between the two materials. The tubes are inserted at such distances apart that the whole of the wall affected by damp shall come within their influence, and they operate by absorbing moisture and removing it by a permanently continuous circulation of the air, the average volume of air moved by each tube being stated at 33 cubic centimetres per second.

Full details relative to the Knapen system will be found in the *Proceedings of the Société des Ingénieurs Civils* for April 1911.

SOUND-RESISTING CONSTRUCTION

Although buildings are not designed and constructed with such special regard to the prevention of sound transmission as they are in respect of fire resistance, a good deal of attention is properly devoted to sound-resisting construction in connexion with floors and interior partitions.

The following table contains values, as given by Molesworth, for the velocity of sound-waves through various substances.

Substance.	Velocity of Sound.
Wet sand	825 feet per second
Contorted rock	1,090 „ „
Air	1,142 „ „
Granite (discontinuous)	1,306 „ „
„ (solid)	1,664 „ „
Water	4,900 „ „
Copper	10,378 „ „
Wood (pine)	11,000 „ „
„ (aspen)	16,700 „ „
Iron	17,500 „ „

It will be noted that air is high in the list, thus confirming the well-known fact that floors and partitions containing hollow spaces are effective in resisting the transmission of sound. The figures for rock suggest the relatively high value of this and kindred materials, and particularly in varieties where the interior structure is such as to intercept and break up sound-waves.

Speaking in general terms of rock, brick, tile, concrete, cement, and plaster, it may be said that the denser, the more uniform, and the more homogeneous the material, the more readily is it penetrated by sound. Thus, solid stone permits the passage of sound more readily than rubble, pressed brick more readily than porous hand-made brick, and cement mortar more readily than concrete.

Timber and metals conduct sound very readily, and have the effect of conveying it to all parts of a building, especially in cases where the material is employed to form a connected framework or skeleton.

While confined air is a bad conductor of sound, moving air has the effect of carrying sound through gaps, and also through the voids in porous materials. Therefore all unintentional openings and crevices permitting the circulation of air from one room to another should be carefully closed, and porous materials should be sealed by an exterior coating impervious to air.

Brown paper and paint are very effective in reducing the transmission of sound through wood and other materials, to which they can be applied suitably and conveniently, while materials such as felt and slag-wool can be usefully employed in absorbing and deadening sound that would otherwise be transmitted freely by timber and structural metals. In dealing with timber, however, care must always be taken to avoid the establishment of conditions favouring the commencement and growth of dry-rot.

In buildings where machinery or apparatus of any kind is installed constituting a source of noise, it is very important to insulate the machinery or apparatus by means of felt or other absorbent material, so as to minimise the direct transmission of sound to floors and other structural parts of the buildings. Such treatment is also valuable for reducing vibration. It will be understood that the insulation of machinery in this manner is necessary in addition to, and not as a substitute for, other precautions against sound transmission.

The measures generally adopted for preventing the passage of sound through ordinary floors are briefly summarised below.

One method is to minimise the number of through joists, with the object of interrupting continuity of sound transmission as much as possible, every fourth or fifth joist being made deeper than the others, for the independent support of the ceiling joists.

Another and a more effective method is to adopt what is termed "double floor" construction, making the floor joists quite independent of the ceiling joists, and supporting the latter from ceiling beams spaced at intervals of about 8 feet apart.

A third method is to place a layer of bituminous felt, or other absorptive material of suitable nature, under the bearing of every girder and joist, and to lay a continuous sheet of similar material under the boarding and over the whole area of the floor, so as to reduce the transmission of sound between the joists and the floor boards.

Various forms of *pugging* are employed with the object of absorbing sound-waves between ceilings and floors. The pugging may consist of loose slag-wool, or other non-conducting material, slabs of fibrous plaster, coke breeze concrete, or of compositions prepared specially for sound-prevention purposes. The pugging is usually carried on *sound-boarding* fixed between the joists, double floors being appropriately treated by placing non-conducting slabs immediately above the ceiling.

Care should always be taken to provide for adequate ventilation in order to avoid the encouragement of dry-rot.

PREVENTION OF DRY-ROT

As distinguished from *wet-rot*, which is the result of chemical decomposition in the growing tree, or in timber saturated with water, and exposed to alternations of moisture and dryness, *dry-rot* is a form of decay due to the attack of fungi.

There are various kinds of fungi causing dry-rot, some requiring considerably more moisture than others. For example, the *Coniophora cerebella*, often mistaken for the more familiar *Merulius lacrymans*, demands so much moisture that it is found chiefly in damp cellars, and in Germany is known as "cellar fungus."

The worst form of dry-rot is clearly that due to the *Merulius lacrymans*, a fungus capable of destroying the sapwood and heartwood of nearly all kinds of timber, and which can be identified by observations denoting the presence, form, and structure of fungal threads inside the wood, fungal sheets and strands outside the wood, and fructifications producing reproductive cells or spores.

Outside the wood, the body, or *mycelium*, of the fungus takes various forms. Thus, on infected wood in a damp situation, snow-white filaments, or *hyphæ*, grow rapidly to form a covering like hoar-frost or cotton-wool; next, the mycelium assumes a more compact form, and spreads like a covering over the wood. The coating sometimes attains considerable thickness, the colour being white, or greyish white, tinged with yellow, brown, rose, or violet. Finally, the mycelium assumes the form of cords, often united like a network, yards in length, and nearly as thick as a lead-pencil. At first white, the cords become grey later, and nearly black when dead.

In order to make clear the objects to be attained by methods intended for the prevention of dry-rot, it is necessary to state briefly the conditions favouring the growth of the fungus. The *Merulius lacrymans* in particular requires food, which is obtained by the production of ferments, exercising a destructive effect on the constituents of the wood attacked. It also requires air for respiration, the oxygen combining with carbon and hydrogen taken in as food, and being given off as carbon dioxide and water. A third essential for the growth of the fungus is a sufficient supply of water.

If the wood is well seasoned and free from infection, it can evidently be protected by covering the surface with an impervious coating of paint or varnish, or by impregnating the interior throughout with a liquid, displacing the air originally contained in the pores.

The absence of water renders thoroughly seasoned wood immune from initial attack by the *Merulius lacrymans*, but it is important to note that when once established, this fungus is able to attack the driest wood, the water necessary being furnished to the growing parts by its natural output of moisture, by conduction from damp wood at a distance, by conduction along the cords of the fungus, and by water of condensation.

As the amount of moisture in wood exposed to the atmosphere is directly proportional to the humidity of the air, and as moving air is always

capable of carrying away surplus moisture from wood or other materials with which it may be in contact, it is highly important that bare wood used in buildings should be exposed as far as possible to currents of air. External coatings of paint, oilcloth, and other impervious materials on badly-seasoned wood always favour the growth of the fungus, either by confining moisture in the wood, or by preventing the dispersion of moisture evaporated from other materials in the immediate vicinity. It must be remembered also that as dry wood will absorb moisture from humid air, external coverings such as oilcloth frequently tend to promote conditions distinctly favourable to the commencement and spread of dry-rot.

While badly ventilated spaces filled with warm and damp stagnant air are those where dry-rot is particularly encouraged, the dry air of living rooms is inimical to the fungus, as also is the displacement of air from wood employed under water.

Timber is often found to be suffering from incipient dry-rot on delivery from a seaport, and it is important to note that even after the most thorough drying the fungus may still retain its vitality. It is possible to kill the fungus by the injection of a powerful antiseptic liquid, but the cost of such treatment renders it impracticable for timber to be used in building construction.

Apart from infection existing in timber as supplied from the yard, there is always a risk that the fungi responsible may be communicated from one building to another, or introduced into a building by wood or other materials conveyed from another building affected by dry-rot.

While the external treatment of wood by paint, varnish, and antiseptic liquids cannot kill fungi already established in the interior, they serve the purpose of protecting the material from infection so long as the coating remains intact and operative.

If the fungus is once allowed to establish a footing, there appears to be no radical cure. In cases where dry-rot is found, the worst parts should be cut out and renewed, the remainder thoroughly cleaned and painted with a solution of cupric sulphate or other antiseptic solution. The best preventive is to use nothing but sound, well-seasoned wood, and to provide for free ventilation in every place where it is employed.

CHAPTER XII

IRON AND STEEL WORK

By E. Fiander Etchells, Hon. A.R.I.B.A., A.M.Inst.C.E., A.M.I.Mech.E.

This chapter is divided into three main sections, dealing with Cast-iron Work, Structural Steelwork, and Rivets and Riveting. Steel skeleton buildings are considered in the succeeding chapter, and the construction of roofs, although constituting an important branch of structural steelwork, is discussed in Part II., so as to form one of a series of chapters dealing in a comprehensive manner with steel and timber roofs, and various kinds of roof coverings.

General information relative to iron and steel is given in Part III., and the theoretical aspects of iron and steel construction are discussed in Part IV.

CAST-IRON WORK

The use of cast-iron in building construction is not now generally considered advisable, but as architects are sometimes required to re-use existing cast-iron beams and pillars, and are sometimes called upon to advise as to the strength of existing cast-iron work under new or changed conditions of loading, some knowledge of the capabilities and limitations of the material is still necessary.

Advantages and Disadvantages of Cast-iron.—The advantages of cast-iron are :

(*a*) Its adaptability to special or ornamental forms ;
(*b*) Its comparative freedom from rust as compared with mild steel.

The following objections have been urged against cast-iron :

(*a*) Its comparative heaviness compared with mild steel ;
(*b*) Its brittleness compared with the ductility of mild steel ;
(*c*) Its liability to contain dangerous flaws ;
(*d*) Its liability to break without warning when cooled suddenly by a jet of water in conflagrations.

Flexural Strength of Cast-iron.—The ultimate strength of cast-iron varies greatly, according to its grade and purpose.

Average for Grey Cast-Iron.—

Tension	9	tons per square inch.
Compression (on short lengths) .	48	,, ,, ,,
Shear	9	,, ,, ,,

Admiralty Requirements.—"The minimum tensile resistance to be 9 tons per square inch, taken on a length of not less than 2 inches."

Permissible Working Stresses.—Taking a safety factor of six on the ultimate stresses given above, we obtain:

Tension	1.5 tons per square inch
Compression (on short lengths)	8.0 " " "
Shear	1.5 " " "

London County Council Working Stresses.—The L.C.C. (General Powers) Act, 1909, Section 22, gives:

Tension	1.5 tons per square inch.
Compression . . .	8.0 " " "
Shear	1.5 " " "
Bearing	10 " " "

Reinforced Cast-iron.—From the foregoing figures it will be seen that the compressive strength of cast-iron is about 5.3 times greater than its tensile strength. In this respect, cast-iron somewhat resembles concrete, which is about ten times stronger in compression than in tension (see Chapter XIV.). Consequently, it is evident that cast-iron can advantageously be reinforced with steel to make good its deficiency in tensile strength. Dr. von Emperger of Vienna has recently applied this principle in the design and construction of reinforced cast-iron pillars and arches.

CAST-IRON BEAMS

Proportions of Flanges.—It is shown in Part IV. that in the case of a horizontal beam with vertical loads and vertical reactions, the total horizontal compression in the top flange is equal to the total horizontal tension in the bottom flange. Assuming a beam (Fig. 225) in which the flange load is 12 tons (*i.e.* 12 tons compression in the top flange and 12 tons tension in the bottom flange), and neglecting every factor except the ratio of the compressive to the tensile stress, the following flange areas would suffice:

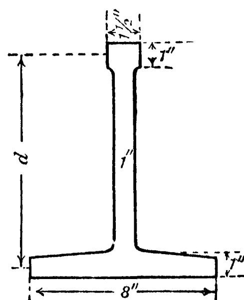


FIG. 225.

Top flange:

$$1\tfrac{1}{2}\ sq.\ in. \times 8\ \frac{tons}{sq.\ in.} = 12 \text{ tons (compression).}$$

Bottom flange:— $8\ sq.\ in. \times 1\tfrac{1}{2}\ \frac{tons}{sq.\ in.} = 12$ tons (tension).

The ratio of the area of the compression flange to that of the tension flange in this case is $\frac{1.5}{8} = \frac{1}{5.3}$. Having been arrived at by temporarily neglecting certain factors, this ratio might lead in many cases to very small compression flanges, in which a bubble or flaw in the casting would

destroy a large proportion of the area, and therefore greatly reduce the compressive strength of the beam. Moreover, the compression flange requires to be stiff, to prevent lateral bending or buckling or side yielding. For these and other reasons the area of the compression flange is often made $\frac{1}{4}$ or even $\frac{1}{3}$ of the area of the tension flange. When such proportions are observed, it is only necessary to calculate the flexural strength of the beam in terms of the tensile stress. The resistance to compression will be satisfactory, but it will, of course, be nece sary to ascertain whether the area of the vertical web multiplied by the shearing stress is sufficient to provide for safely withstanding the shearing force at any cross-section.

Beams on which the load is applied all on one side must be much stiffer than beams on which the loads are balanced or applied in the plane of the web. This latter condition is usually assumed in text-books and tables.

Thickness of Flanges.—The thickness of the tension flange should not be less than $\frac{1}{12}$ of the breadth of the flange. The thickness of the compression flange and of the web should generally be about the same as that of the tension flange.

Area of Tension Flange.—The area of the tension flange necessary to carry a given uniformly distributed load may be found by the approximate rule:

$$A = \frac{WL}{d}.$$

Where A = *area* of the tension flange in square inches, d = effective *depth* of the beam in inches (measured between the centres of gravity of the two flanges), L = effective *length* of beam measured between the centres of bearings *(in feet)*, W = *working* load in tons (uniformly distributed working load inclusive of the weight of the beam itself).

Example.—Let $d=15$ inches, W = 10 tons, and L = 12 feet. Then A = 8 square inches.

Conversely, the safe uniformly distributed load on a cast-iron beam of known proportions may be ascertained by the approximate rule:

$$W = \frac{Ad}{L}.$$

Example.—Let A = 8 square inches, $d=15$ inches, and L = 12 feet. Then W = 10 tons.

The two foregoing rules are based upon the flexural tensile stress of 1½ tons per square inch at the centre of gravity of the tension flange.

Breadth of Tension Flange.—The breadth of the tension flange should not be less than $\frac{1}{24}$ of the span, and is often much wider in good designs.

Details of Design.—Abrupt changes in the thickness of castings lead to unequal rates of cooling, which set up initial internal stresses in the metal, and may cause fracture at the parts where there is any sudden change in the thickness or direction of the metal. In order to prevent cracking due to unequal contraction, both the flanges and the web are

often made of the same thickness throughout, as in Fig. 226. This procedure also makes the proportioning of the flanges a matter of simple mental arithmetic, inasmuch as the areas of the flanges are then proportional to their breadths. In cases where the flanges are not of equal thickness, the web should be gradually tapered from top to bottom, so that its thickness near the top is the same as the thickness of the upper flange, and the thickness near the bottom is the same as that of the lower flange. Flanges of equal thickness are preferable.

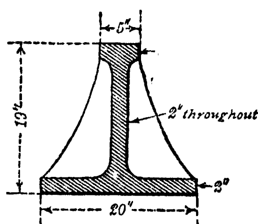


FIG. 226.

Re-entrant Angles.—All re-entrant angles should be rounded, as abrupt changes of direction are a source of weakness. Moreover, a re-entrant angle in the casting would necessitate a salient angle in the mould; and the flow of molten metal might wash away the salient angles of the moulded sand.

Perforated Webs.—As shown in Part IV., the shearing forces in a beam are resisted principally by the web. In cases where the shearing forces are small, beams or cantilevers are sometimes lightened by piercing the web with holes, as in Fig. 227. Perforated webs, however, are apt to cool at unequal rates. The metal round the holes cools quickly and shrinks, and is liable to cause objectionable cracks. Sometimes the metal round the hole is thickened, or is strengthened by a circular rim, but such a rim merely tends to neutralise the saving of weight resulting from the perforation of the web. On the whole, unperforated webs are considered preferable where strength is the chief consideration. In cases where it is desired to provide a cantilever of decorative character, a complicated design may be adopted, when the massiveness of the design compensates for the greater risk of initial internal stresses due to unequal rates of cooling and varying degrees of shrinkage. The nominal stress in such cases is usually low.

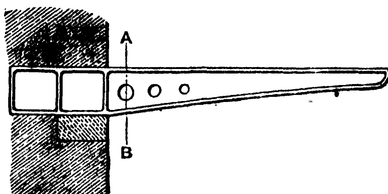


FIG. 227.—Elevation.

Limitation of Span.—It is not considered economical or advisable to use cast-iron beams of more than about 20 feet span; nevertheless there are many cast-iron beams of greater span in existing buildings.

Ratio of Depth to Span.—The depth of cast-iron beams should be ordinarily from $\frac{1}{10}$ to $\frac{1}{12}$ of the span, but sometimes the ratio of $\frac{1}{20}$ has been adopted.

Camber.—To prevent undue sagging or unsightly drooping below a horizontal line, long beams are usually designed with an upward camber, or rise, towards the middle of their span. The camber should always be well in excess of the greatest possible deflection. Cast-iron beams some-

times have a camber of about 1 inch in 15 feet of span, whereas steel-plate girders may have a camber of 1 inch in 30 feet. Small cast-iron beams, like small steel joists, are used without any camber.

Bearing Area.—The ends of cast-iron beams are sometimes widened so as to afford a greater bearing area, and give a greater steadiness to the beam.

Bedding of Beams.—Cast-iron girders are not placed directly upon stone templates, but are usually bedded on tarred felt, or on a piece of asbestos board, or on any of the thin patent roofing materials, which are claimed to be imperishable and rot proof. Sheet-lead is not generally looked upon with favour, as it will flow under continuous pressure.

Fixity of Ends.—Cast-iron beams of ordinary section should never be fixed at the ends, and should never be made continuous over a support, as either procedure would throw the small top flange into tension, and might create a very real danger.

Summary of Limiting Proportions of Cast-iron Beams.—The rules which summarise good practice may be set out as follows:

Maximum effective span = 20 feet.
Minimum overall depth = $\frac{1}{12}$ of span.
Minimum breadth of tension flange = $\frac{1}{24}$ of span.
Minimum thickness of tension flange = $\frac{1}{12}$ of its breadth.
Thickness of compression flange = thickness of tension flange.
Thickness of web = thickness of tension flange.
Minimum area of compression flange for balanced loads (*i.e.* not lopsided loading) = $\frac{1}{4}$ area of tension flange.
Minimum camber = 1 inch in 15 feet.

It should be noted that the above are maximum and minimum limits, and that modification within the limits is permissible.

Cast-Iron Pillars

Cast-iron is used for unprotected pillars of ornamental character, as on railway-station platforms. It is also used for light pillars supporting canopies, galleries, or other light work. It is rarely used in the skeleton framework of modern buildings.

Rules for General Guidance.—Where cast-iron pillars are used in buildings, the following rules are recommended:

Least Diameter.—The least diameter should not be less than 5 or 6 inches.

Ratio of Height to Diameter.—The ratio of height to diameter should not exceed 20, and a lesser ratio would be more economical, because the permissible stress would be higher. The L.C.C. (General Powers) Act, 1909, limits the length of a cast-iron pillar to eighty times the gyration radius.

Thickness of Metal.—The metal in a pillar should not be in any part of less thickness than $\frac{3}{4}$ inch or $\frac{1}{12}$ of the least diameter of the pillar, whichever is the greater.

Cap and Base.—The cap and base of every pillar should be in one piece with the shaft, where practicable (see Fig. 228).

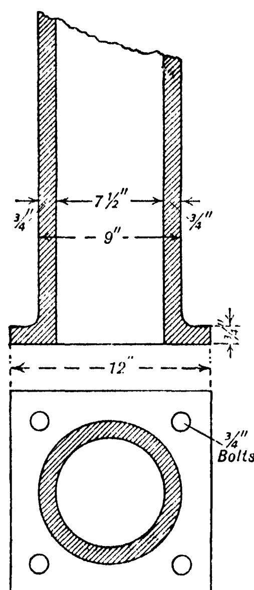


FIG. 228.

Position of Joints.—All joints between superimposed pillars should be at, or as near as may be reasonably practicable to, the level of a girder properly secured to such pillars.

Bolts at Joints.—All joints between superimposed pillars should have at least four bolts of not less diameter than the least thickness of metal in the pillar. If more than four bolts are used their diameter may be reduced proportionately, but no bolt should be of less than ¾-inch diameter.

STRUCTURAL STEELWORK

This section includes three divisions, dealing with Beams, Compression Members, and Grillages respectively.

Market Forms of Structural Steel.—Notes on these are given in Part III. Reference should also be made to the publications of the Engineering Standards Committee, giving the sizes and properties of British Standard Sections, and to the handbooks of the various steel manufacturers and merchants.

BEAMS

Definition.—The term *beam* includes any joist, girder, bearer, lintel, bressummer, cantilever, rail, purlin, or any other member carrying transverse loads and having transverse reactions. Beams may be laid at any angle, may be curved, straight, or cranked, and may have any form of cross-section.

Joists.—The beams used in structural steelwork are usually of I-section. The rolled I-section is frequently referred to as a joist, but as a *joist* is literally "that on which anything lies, as on a bed," the term *joist* is strictly only applicable when the I-section is used as a beam, and not when used as a pillar.

Girders.—A main beam which picks up and supports the ends of a series of subsidiary beams is said to "gird" those subsidiary beams. Therefore a girder is, strictly, a main beam, or an outside beam "girding" other beams. The term is, however, sometimes used in a wider sense for certain legislative purposes.

Effective Span to be Taken.—The *clear span* of a beam is the minimum distance between the inner faces of the supports, and the *effective span* is the distance between the centres of bearings. For calculations of permis-

sible loads, deflection, and bending moments, the effective span should be taken.

Ends of Beams.—In most cases the ends of beams should be taken as freely supported. Tables purporting to give the loads on beams should be examined to see that they are calculated on this assumption.

Continuous beams and beams with fixed ends are considered in Part IV.

Allowance for Weight of Beams.—In calculating the working load on beams, allowance should be made for the weight of the beam itself. Experience shows, however, that with joists of short or medium span the weight of the joist will be only a small fraction of the total load. In such cases a small surplus of the permissible load over the superimposed load will be sufficient to cover the dead load of the joist without specific calculation.

Area of Tension Flange.—For a joist, compound girder, plate girder, box girder, or other similar member with ends freely supported, to carry a uniformly distributed load with an average flange stress of 7.5 tons per square inch, the requisite net area (in square inches) of the tension flange, after deducting rivet holes, may be obtained from the approximate equation :

$$A = \frac{W}{60}\left(\frac{l}{d}\right).$$

When the effective length is expressed in feet, then the equation reduces down to

$$A = \frac{WL}{5d},$$

where A = net *area* of the tension flange in square inches (see area in black in Fig. 229), d = effective *depth* of the beam in inches, *i.e.* the distance between the centres of gravity of the two flanges, l = *length* of effective span in inches, L = effective *length* in feet, W = total permissible *weight* or *working* load (in tons), including *weight* of beam itself.

Area of Compression Flange.—The area of the compression flange should be at least equal to that of the tension flange. Further notes on this point will be found under the head of "Plate Girders," p. 163.

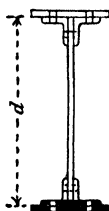


FIG. 229.

JOISTS

Selection of Rolled Sections.—The selection of a joist in any given case may depend upon many factors, including load, span, nature of connexions, available headroom, possibility of early delivery, desirability of uniformity in design, and relative economy of different sections.

Depth.—The depth of joists usually varies from $\frac{1}{12}$ to $\frac{1}{24}$ of the span. The higher this ratio is the stiffer will be the beam.

Ratio of Strength to Weight.—Other conditions being equal, a section

should be selected which has a high ratio of total safe load to weight of metal, either for the beam as a whole, or per foot run.

Standard Connexions.—A typical standard end connexion and splice for joists are shown in Fig. 230. It should be borne in mind that standard connexions are only for normal cases, and that special conditions may require special connexions.

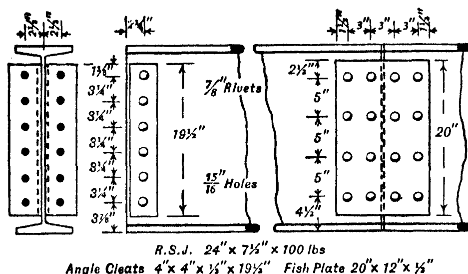


FIG. 230.

In the case of short spans, the number of rivets shown may be insufficient to carry the load which the joist is capable of carrying. The fish-plates shown are only for connecting lengths of joists over supports. Where a joist requires jointing at some point between the supports, the connexion must be specially designed, and should be considerably heavier than in Fig. 230. In the best work full cover plates are placed over both flanges, where practicable, as it is difficult to ensure perfect butting of the

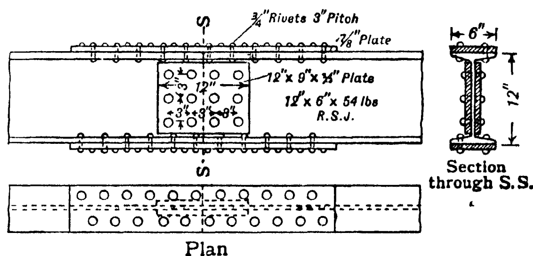


FIG. 231.—Joint designed to resist Flexure.

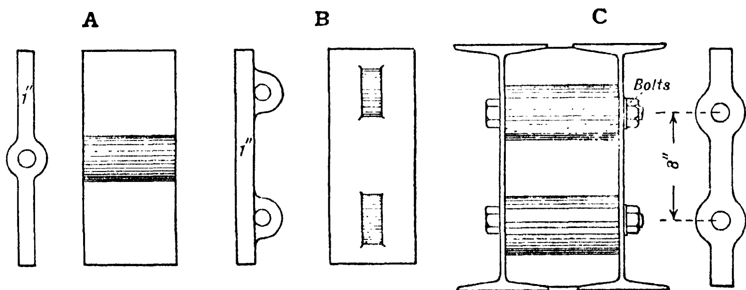
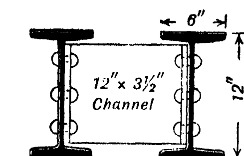


FIG. 232.

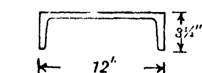
flanges and perfect centring of the rivets simultaneously (see Fig. 231). In some contracts obtained on a competitive basis, the cover plate on the

compression flange is frequently shortened, and sometimes omitted, but these practices are not commendable.

Twin Beams.—Whenever two or more beams are arranged alongside, and intended to act together, they should be connected by bolts and iron *separators* (Fig. 232), or by diaphragms connecting the webs (Fig. 233), or by ties riveted across the flange plates. The connexions, if rigid, tend to ensure equality in the distribution of load, and to increase the lateral



Cross Section of twin joists showing diaphragm between



• Plan of diaphragm with joists removed

Fig. 233.

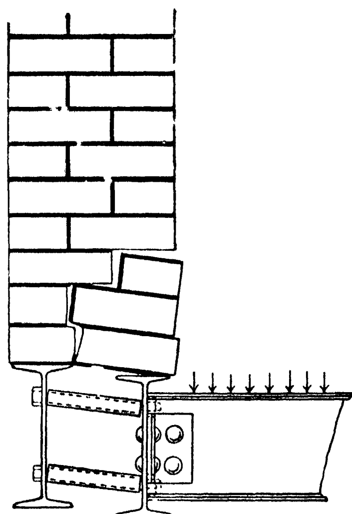


Fig. 234.

stiffness of the beams. Twin beams should be connected over all supports, and immediately under or at all concentrated loads.

In the case of a pair of beams acting as a bressummer, with a cross beam trimmed in on one side, a vertically rigid connexion must be made between the webs. The necessity for this is indicated in Fig. 234, where ferrules and bolts are shown to be inadequate to prevent unequal deflections.

GIRDERS

Principal Types.—The principal types of girders are *compound*, *plate*, *box*, and *lattice* girders.

Compound Girders.—When single joists are insufficient to carry the given load, compound girders are convenient and economical. Typical forms, built up of joists and plates, are shown in Fig. 235.

Plate Girders.—A plate girder is one built up of plates and angles (Fig. 236). Plate girders are more expensive than joists, weight for weight, on account of the extra labour involved. Either joists or compound girders should be used where practicable. (In this connexion it may be mentioned that joists of British Standard Steel may be obtained up to 24 inches deep, and *broad flange* joists of milder steel than the British

Standard up to 40 inches deep. The web would be thicker than that of a plate girder of corresponding depth, but the thicker web may obviate the

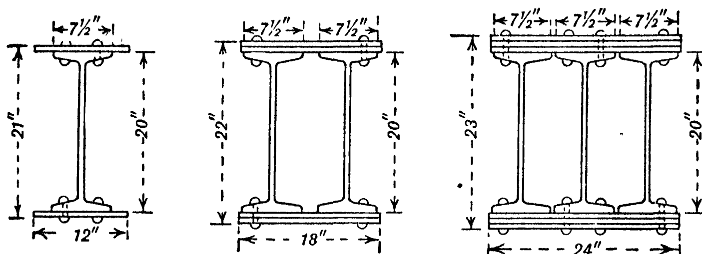


FIG. 235.

need for web stiffeners, except over the abutments and under concentrated loads.)

Depth.—The depth of plate girders varies from $\frac{1}{10}$ to $\frac{1}{16}$ of the span. The greater the depth, the less area will be required in the flanges, but the depth and thickness of the web will be increased. A depth of $\frac{1}{12}$ of the span is stated to give the greatest strength for the least dead load. The final selection of a depth may, however, be governed by the available headroom, and by the possibilities of delivery within a specified time. The adoption of standard sizes is to be recommended wherever practicable. Standard depths vary from about 2 feet 6 inches, advancing evenly by 2 inches to about 3 feet 6 inches in ordinary practice. When the depths of the webs are even multiples of 2 inches, market sizes of plates can be used; thus avoiding the cost of extra shearing.



FIG. 236.

Thickness of Web.—The thinner the plate the more liable it is to buckle, and the sooner it will be destroyed by corrosion. The customary thicknesses of web plates in building construction are $\frac{3}{8}$ and $\frac{1}{2}$ inch. Plates of less thickness than $\frac{3}{8}$ inch should not be used, and a greater thickness than $\frac{1}{2}$ inch is very rare. The thickness of the web plates should be at least $\frac{1}{48}$ of the depth, unless stiffeners are used, at a distance apart not exceeding the depth of the web plate.

Camber.—A deflection of $\frac{1}{400}$ of the span is permissible in steel beams, with a static uniformly distributed load and ends freely supported. Plate girders should be constructed with an upward camber somewhat greater than the permissible downward deflection, so that they will not sag even when fully loaded. An initial upward camber of $\frac{1}{360}$ of the span is sufficient, *i.e.*, 1 inch in 30 feet of span.

Area of Tension Flange.—Approximate rules for calculating the area of tension flanges are given on p. 161. In plate girders, the net area of the horizontal limbs of the main angles may be included in the net area of the tension flange.

Area of Compression Flange.—As previously stated, the area of the compression flange should be at least equal to that of the tension flange.

It is sometimes urged that as machine-driven rivets entirely fill the rivet holes, the full cross-sectional area of plate and rivet can be taken, and therefore the compression flange need not be so large as for the tension flange. This conclusion involves a fallacy, in the assumption that the compression flange can be stressed as high as the tension flange, with the same degree of safety. The compression flange tends to buckle, and the stress should be somewhat reduced. In practice the compressive stress is reduced somewhat below the tensile stress by the simple expedient of making the *gross* area of both flanges identical. Then under working conditions the effective area of the tension flange is the *net* area, while the effective area of the compression flange is the *gross* area, including the rivets. The compression flange should also be stayed laterally at both ends and at other convenient places. wherever practicable.

Side Yielding of Compression Flange.—The compression flange should be secured against side yielding or buckling whenever its length exceeds twenty-four times its width. The London Building Act permits a ratio of 30, but a lesser ratio is preferable where practicable. Mr. Alexander Drew has recommended the following rule:

Length of Compression Flange.	*Stress.*
20 times flange width . . .	Full stress
25 times flange width . . .	95 per cent of full stress
30 times flange width . . .	90 per cent of full stress.

Flange Stiffeners.—Flange stiffeners (Fig. 237) serve to steady the flanges, particularly the compression flange. They also stiffen the web very effectively. The stiffening is effected by cranking vertical angles or putting in gussets and angles so that the compression flange is held square to the web and parallel to the tension flange. Flange stiffeners or their equivalent should be used on all built-up plate girders which occur in the outside walls of buildings, for the floors of such buildings act as an unbalanced side load on the girders. The stiffeners should never be further apart than about twice the depth of the girder. Flange stiffeners may not be necessary for interior girders of buildings, as the cross girders and floor joists may stiffen and strut the main girders effectively.

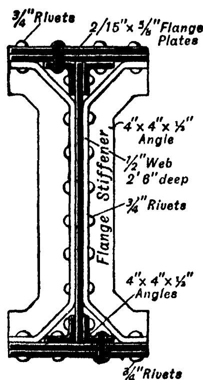


FIG. 237.
Flange Stiffener.

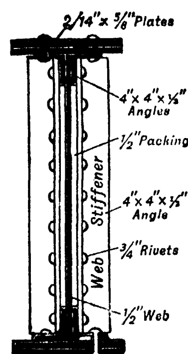


FIG. 238.
Web Stiffener.

Web Stiffeners.—Web stiffeners (Fig. 238) are primarily used to prevent the tendency of the web to buckle under compressive stress. They should be placed at the extreme ends of girders, over the bearing

edges of the abutments or other supports, under the bearing edges of all concentrated loads (Fig. 239), and at distances apart not exceeding the depth of the web.

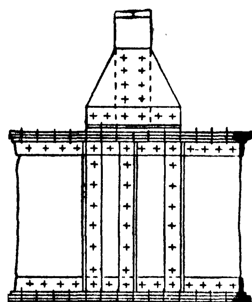
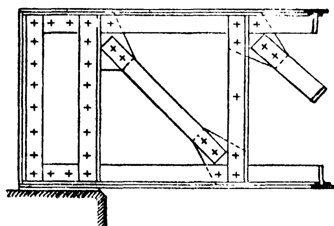


FIG. 239.—Position of Web Stiffeners.

When web stiffeners are provided flange stiffeners are sometimes omitted. Girders are sometimes designed with web and flange stiffeners alternating with one another. In such a case the web would be divided into square or rectangular panels, and every second stiffener would hold the flange.

A plate girder with web stiffeners may be likened to a lattice girder with vertical struts, the tensions being assumed to be transmitted diagonally through a strip of the web. The strip should be assumed to have a limited width (see Fig. 240).

Stiffeners should be calculated as hinge-ended struts, free to buckle in a direction normal to the plane of the web. The stiffeners should be in pairs on opposite sides of the web, the pair of stiffeners constituting one strut. It is usual to design the strut for the worst case, and then use that section of strut throughout



Lattice Girder.

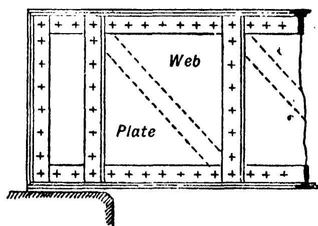


Plate Girder.

FIG. 240.

the whole of the girder. It is considered that the advantages of uniformity and consequent simplicity of construction outweigh any supposed advantages of refinement in adjusting the section of each stiffener to its own estimated load. There is also a general need for stiffness in a plate girder ; a need which is too indefinite and variable a factor to be included in detailed calculations. Consequently good designs frequently have stiffeners which would seem far in excess of the requirements of calculations which neglect the secondary stresses, and all the complexity of actual conditions.

Although angle sections do not make symmetrical struts, or stiffeners, they are convenient, because the single line of rivets does not disturb the uniform pitch of the riveting in the main angles, as would happen if tee sections were used.

BOX GIRDERS

Sometimes wide plate girders are provided with two separate webs. They are then known as box girders. Such girders have considerable lateral strength, and are very suitable for carrying side loads or thick walls.

Box girders should have interior web stiffeners or diaphragms, which should be machined square, and finished dead flush with the backs of the main angles, otherwise such girders may develop a twist or "get into winding," as shown in Fig. 241. An effective diaphragm for a box girder is shown in Fig. 242.

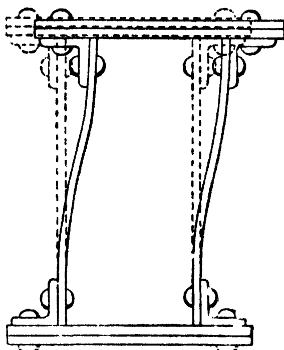


Fig. 241.—Cross-section of Box Girder without Diaphragms.

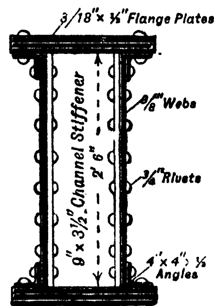


Fig. 242.—Box Girder with Diaphragms.

LATTICE GIRDERS

As the span of a girder is increased, there is a simultaneous increase in the ratio of the dead weight of the girder to the

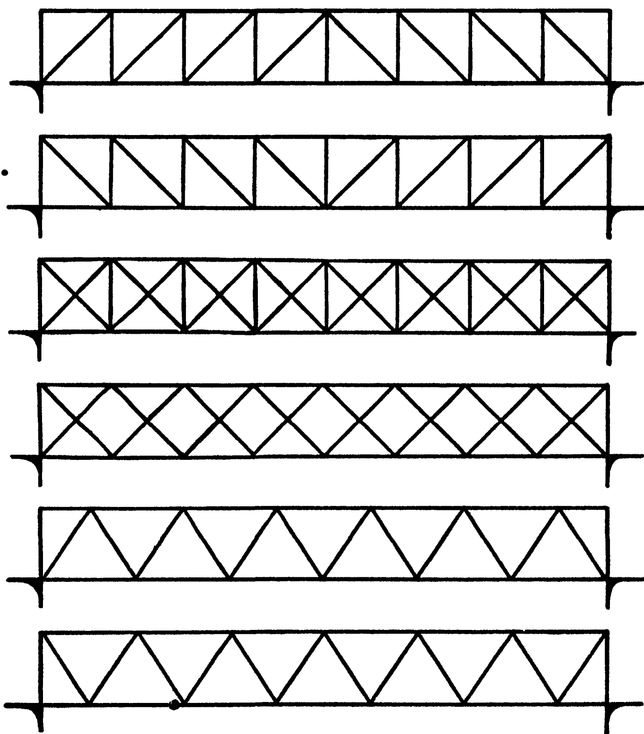


Fig. 243.—Typical Forms of Lattice Girders.

superimposed load it will safely carry. In the case of long spans every effort is made to lessen the dead weight by cutting out as much of the web as possible, until only lattice work is left. In most British buildings the spans are not sufficient to justify the extra cost of labour; joists, compound girders, plate girders, and box girders fulfilling all ordinary needs, although lattice girders are used occasionally.

Typical lattice girders are shown diagrammatically in Fig. 243.

COMPRESSION MEMBERS

Classification and Definitions.—Column and stanchion, post and pillar, raking strut and flying shore, are but particular instances of structural forms which come under the general heading of compression members.

Strut Defined.—The term *strut* is the most comprehensive of the specific terms applied to compression members, since a strut may be of any form of cross-section, at any slope or angle, and may lie horizontally or stand vertically.

Regulations made under the London County Council (General Powers) Act, 1909, state that, "The term *strut* means any compression member at any angle." The term *strut* includes the compression members of lattice girders and roof trusses, and any subsidiary support, whether vertical or otherwise.

Pillar Defined.—The word *pillar* is the next most comprehensive, since a pillar may be of any form of cross-section, but must be vertical.

Regulations made under Section 23 of the London County Council (General Powers) Act, 1909, state that, "The term *pillar* shall be deemed to include any pillar, pier, post, column, detached support, or any other *vertical* compression number."

Stanchion Defined.—The term *stanchion* is used for a steel pillar of any shape of cross-section except circular.

Column Defined.—The word *column* is the least comprehensive of the series, since a column must be circular in cross-section, and vertical.

Economical Form of Cross-Section.—The further the metal is removed from the axis of the pillar, the more efficacious that metal will be in resisting any tendency to buckle. Therefore, weight for weight, a hollow pillar is stronger than a solid pillar.

Typical forms of cross-sections are shown in Fig. 244. For small loads ordinary I-sections will generally be found sufficient. For greater loads, built-up pillars will be necessary. In selecting a section of a large pillar, choose one in which the bulk of the metal is away from the centre of gravity of the pillar. Also arrange the pillar so that it will be at the best advantage in resisting any tendency to bend, if subject to wind load or other eccentric load.

Diameter of Pillars.—The diameter of a pillar of given height usually represents a compromise between conflicting requirements. On the one hand, the smaller the diameter the greater will be the available floor space. On the other hand, the larger the diameter the greater will be the permissible load per square inch on the steel. The least diameter of pillars in practice usually varies from about $\frac{1}{15}$ to $\frac{1}{30}$ of the height.

Eccentricity of Loading and Flexure of Pillars.—In practice it is difficult to ensure that the load will come right on the exact centre of the pillar, and any load which does not come on to the exact centre of a perfectly straight and absolutely vertical pillar will tend to bend that pillar. In ordinary cases of equal loads on either side of a pillar, the bending tendencies are, more or less, mutually counterbalanced.

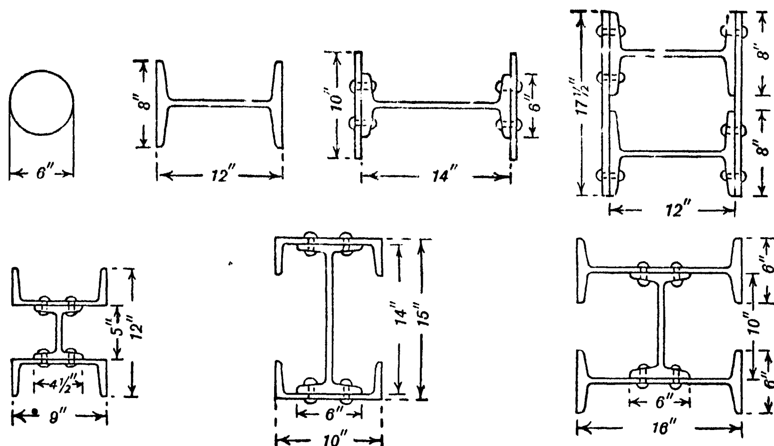


FIG. 244.—Cross-sections of Pillars.

In the case of the pillars in the external walls of a building, there will usually be balanced loading from the bressummers in the external walls, and an unbalanced load from any main floor beams or girders running into the pillar in the external wall. This unbalanced loading may produce greater stresses than a central load of twice the amount.

In order to reduce the bending tendency, pillar caps should be as small as practicable. On the other hand, the pillar bases should be as large as practicable, so as to ensure a firm and stable base. When the axis of the pillar at the base is adequately fixed in position and direction, a greater compressive stress is permissible on the steel.

Brackets and Cleats.—Some typical examples of brackets for columns are illustrated in Fig. 245. If brackets and cleats are not reasonably strong, the unbraced skeleton will be lacking in stiffness, and will be rickety and weak-kneed.

Pillar Caps and Bases.—Fig. 246 shows typical pillar caps. Fig. 247 shows typical bases.

Solid Columns.—Round bars can be obtained for use as solid columns. The customary diameters vary from 4 to 12 inches, advancing by half inches.

Cap, and Bases.—The ends of the column are turned down to form a shoulder (see Fig. 248). The caps and bases are formed of heavy steel slabs, with a central hole to receive the column. The usual thickness of the slab is one-half of the diameter of the column for the smaller pillars.

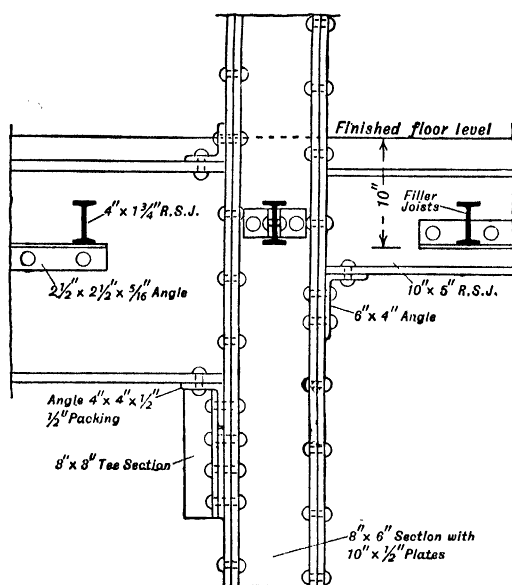


FIG. 245.—Typical Cleats.

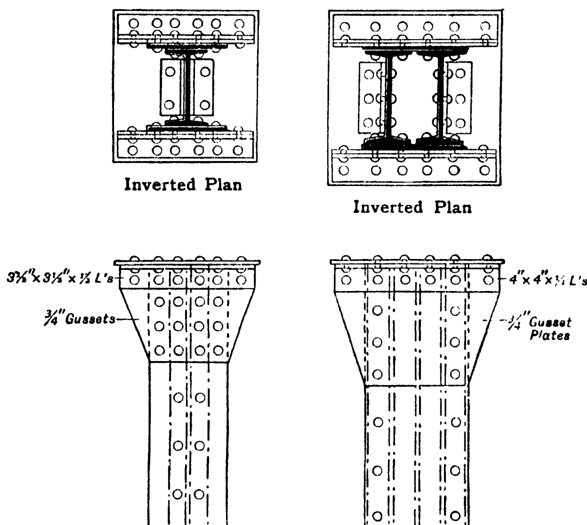
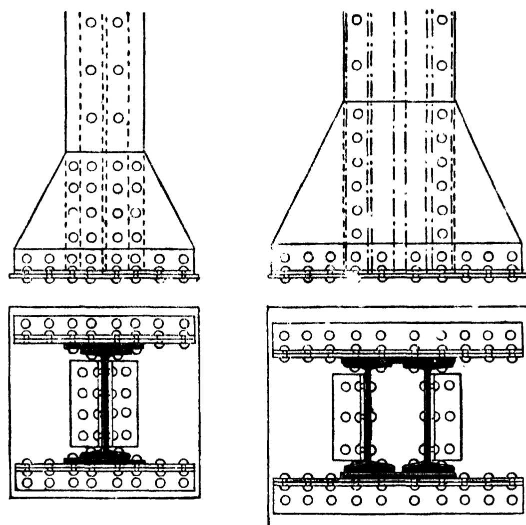


FIG. 246.—Typical Caps.

For the larger pillars, the necessary thickness of slab cap is determined by calculation. The slabs are heated and shrunk on to the column ends.

Economy.—The solid pillar is economical of floor space but not of steel, as the massing of the steel in the centre of the pillar is not advantageous



2' [illegible] × 2' 0" × ¾" Base plate.
¾" Gusset plates.
14" × 6" I-Section.
Two 10" × ½" Plates in shaft.
4" × 4" × ½" Angles.

2' 9" × 2' 4" × ¾" Base plate.
¾" Gusset plates.
Two 14" × 6" I-Section.
Two 14" × ½" Plates in shaft.
4" × 4" × ½" Angles.

FIG. 247.—Typical Bases.

in the resistance to flexure. The narrow caps and bases of the pillar, and the indefinite amount of the frictional grip between pillar and slab do not justify any general assumptions of perfect fixity of ends. Neither are the ends freely hinged. They conform to an intermediate degree of fixity. They may be considered as having flat ends.

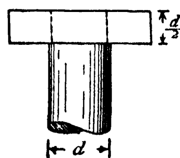


FIG. 248.—Slab Cap for Solid Steel Column.

Gyration Radius : Virtual Radius. — For solid columns, *i.e.* for solid pillars circular in cross-section, the virtual radius is one-half of the actual radius. In other words, the gyration radius is equal to one-half the maximum radius, or one-fourth of the diameter. This ratio is only true for solid circular sections.

GRILLAGES

A grillage consists of several parallel joists used for spreading the concentrated load from a pillar over the necessary area of the foundations.

In cases where there is sufficient depth of concrete to distribute concentrated pillar loads within an angle of 30 degrees measured from the

vertical, as shown in Fig. 249, strong mass concrete will be sufficient. In cases where a more rapid distribution of the load is desired, as shown in Fig. 250, steel joists are used. Grillages may be composed of one, two, three, or even four tiers of joists. Fig. 251 shows a typical four-tier grillage.

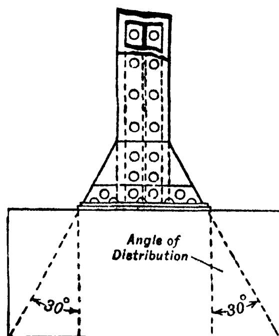


FIG. 249.—Plain Concrete Foundation Block.

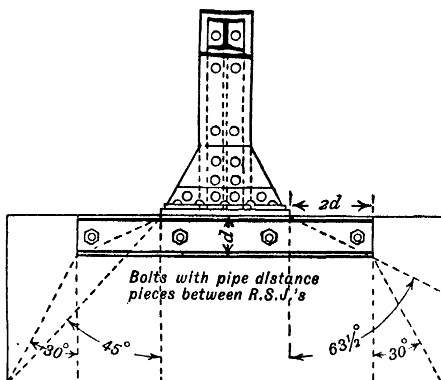


FIG. 250.—One-tier Grillage.

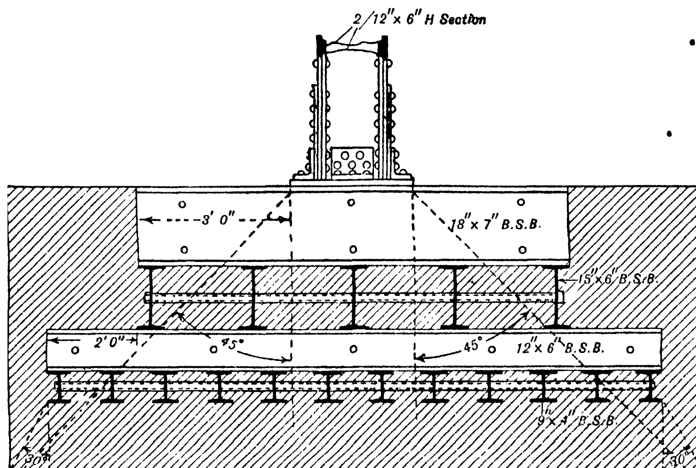


FIG. 251.—Diagram showing Projection of Grillage Joists, Depth of Concrete, and Distribution or Dispersion Angles.

Buckling of Webs.—The web of the joists in grillages should be calculated to resist buckling, as it is not possible to ensure the concrete filling being a perfectly tight fit after such concrete has hardened. It is desirable, however, that the outer joists in any given tier should be tied in by cross-ties or bolts to keep the joists in position, and as an additional means of stiffening the grillage generally (see Fig. 251).

Flexural Resistance.—Many of the current rules for determining the

strength of grillages are based on the assumption that a grillage joist acts like a pair of cantilevers back to back, with loads and reactions inverted. It is, however, very doubtful whether the assumption is justifiable. Where a long and shallow joist is laid on a massive hardened concrete block, the rigidity of the block, compared with the elasticity of the joist, would prevent the joist from taking up such deflection as would bring the whole of its length into effective use as a pair of cantilevers back to back. In other words, the underside of a slender joist with uniformly distributed pressure would be slightly curved, whilst the surface of a concrete block under uniformly distributed pressure would be uniformly depressed, and such depressed surface would be straight and level. The conditions of uniform pressure on slender joist and concrete block are, therefore, not compatible with each other.

The intensity of the upward pressure must of necessity be greatest under or near the base of the pillar (see Fig. 252). Some engineers take into account only such a projection of the cantilever grillage as lies within a line making an angle of 60 degrees with the vertical, and passing through the extreme edge of the base plate of the stanchion. In these cases the crippling stress of the web of the grillage joist is the governing factor, and calculations for bending moment are unnecessary. Other engineers restrict the length of the projecting portion of the cantilever beyond the edge of the base to twice the depth of the joist (see Fig. 250). This corresponds with an angle of 63½ degrees, measured from the vertical.

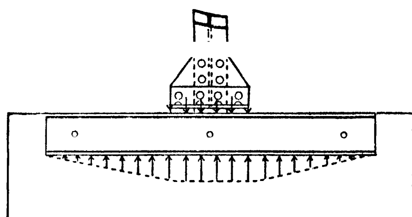


FIG. 252. — Approximate Distribution of Pressure of Joist on Concrete Foundation Block.

Depth of Concrete.—If there should be any extensive tension cracks on the underside of the concrete, they would admit moisture, and might lead to the corrosion of the embedded steel, and the consequent disruption of the adjacent concrete. These remarks also apply to the shallow slabs of reinforced concrete which are sometimes placed under steel pillars, and buried in the earth. Foundation blocks and slabs, whether of reinforced concrete or whether containing steel grillages, should be as stiff as possible, to offer the maximum resistance to curvature or deflection. The steel joists should be used to distribute the load over the concrete, not to prevent cracked slabs from cracking further.

It is undesirable to allow the concrete in grillage or similar foundations to project beyond the base plate of the stanchion to a greater extent than the overall depth of the concrete (see Fig. 250). This will give an angle of distribution of 45 degrees. For plain concrete it is advisable to restrict the angle to 30 degrees from the vertical (see Fig. 249).

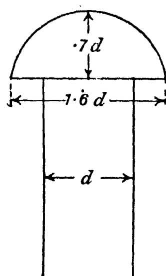
Space between Joists.—The joists in a grillage should be kept far enough apart to enable concrete to be filled between and properly rammed, so as to fill completely all spaces or cavities.

RIVETS AND RIVETING

RIVETS

New British Standard Forms and Proportions.—The two principal forms of rivet heads used in building construction are shown in Fig. 253. The new proportions for countersunk rivets were introduced in 1914. Countersunk rivets are only used where a flush face is required, as on the seatings of girders, and on the bearing surfaces of pillar caps and bases. In all other cases snap heads are adopted.

Grip of a Rivet.—The *grip* of a rivet, or the grip length, is the distance between the heads of the rivet when closed. In the case of



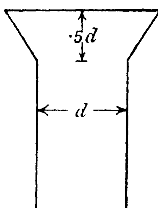


FIG. 253.

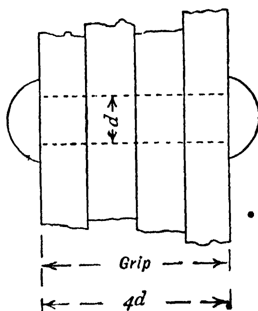


FIG. 254.

countersunk heads the grip is measured to the flush face of the head. The maximum grip should not exceed four times the diameter of the rivet, so that where the cumulative thickness of plate exceeds 3 inches, a rivet of larger diameter than $\frac{3}{4}$ inch will be necessary (see Fig. 254).

Diameter of Rivets.—There are many rules for finding what is stated to be the best diameter of a rivet. Most of these rules are only applicable to a particular class of work; for example, rules for riveting in light tank work would not be applicable to heavy boiler work or ship work. Many rules have been proposed in respect to the rivets in structural work, but there is an increasing consensus of opinion which leads to the neglect of the refinements of rules which would vary the diameter of rivets according to every change of plate thickness or of pitch.

Customary Diameters.—Formerly the commonest rivet diameters were $\frac{5}{8}$ inch, $\frac{3}{4}$ inch, $\frac{7}{8}$ inch, and 1 inch. Nearly all building work is now done with $\frac{3}{4}$-inch and $\frac{7}{8}$-inch rivets. Many designers use $\frac{3}{4}$-inch diameter rivets for the bulk of their work, and only use $\frac{7}{8}$-inch rivets for the bases of large pillars and for the ends of heavy built-up girders, and the flanges of the larger compound girders. A safe note to be put on all structural drawings would be, "All rivets to be of $\frac{3}{4}$-inch diameter except where otherwise shown."

PITCH OF RIVETS

Pitch Defined.—The distance between the centres of consecutive rivets is called the *pitch*, and may be measured longitudinally, diagonally, or crosswise in relation to the direction of the flanges.

In Fig. 255 *lp* = longitudinal pitch, *dp* = diagonal pitch, *cp* = cross pitch. When the term pitch is used without any qualification, the context should indicate whether the longitudinal or other pitch is intended.

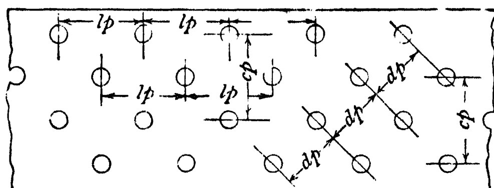


FIG. 255.

lp = Longitudinal pitch. *cp* = Cross pitch. *dp* = Diagonal pitch.

Uniform Distribution of Rivets *v.* Even Pitch. — In former practice there was often a uniform distribution of rivets. A given stretch of riveting was divided up into a definite and prearranged number of pitches, so that the pitch often worked out to fractional numbers, frequently involving odd thirty seconds of an inch. In modern practice the pitch varies by even inches. Any deficit or surplus pitch is made up by a single odd dimension at the end of the stretch.

Factors Governing Pitch.—In structural work, if the pitch of rivets is too great moisture may creep in between the plates and set up corrosion. In the case of steel to be encased in solid concrete, the risk of corrosion is, of course, lessened, but there are so many other factors governing the pitch of rivets that the influence of any one factor becomes merged in a general result. In the case of plates in compression, too great a pitch between the rivets would allow the plates to buckle, as in Fig. 256. There is also a general necessity for homogeneity in built-up pillars or girders, in order that such members shall, as far as possible, act as effectively as single sections.



FIG. 256.

Dominant Factor.—Shearing stress is a very important factor, making it necessary to vary the pitch of rivets to suit particular cases.

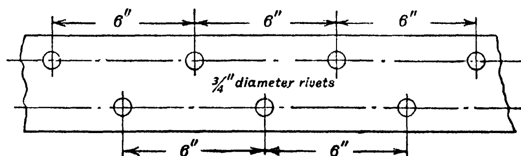


FIG. 257.

Maximum Pitch.—Whether in girders or pillars, the pitch should never exceed sixteen times the thickness of the thinnest plate through

which the rivet passes, and should never be more than 6 inches, whichever is the lesser. Plates less than ⅜ inch thick are not used in the flanges of pillars or girders. Providing the plates are not less than ⅜ inch thick, the rule for maximum pitch of riveting simplifies down to the following: The pitch of rivet should not exceed 6 inches, whether in pillars or girders.

The pitch is measured in a continuous straight line. Fig. 257 shows two lines of riveting at 6 inches pitch. It is either a mistake or reprehensible sharp practice to measure the longitudinal pitch between rivets lying along different rows or lines.

Customary Pitch in Pillars.—The pitch of rivets throughout the shaft of compound stanchions will generally be sufficient at 6 inches, provided that no plate is less than ⅜ inch thick. At caps and bases and at brackets and similar connexions closer spacing is generally necessary.

Customary Pitch in Girders.—In the case of girders the customary pitches are 3 inches, 4 inches, and 6 inches, the latter being generally sufficient towards the centre of the span, but at the ends a closer spacing is usually necessary, particularly if the girder is a short stiff one, and fully loaded. This closer spacing of the rivets towards the supports is a point too often omitted in the designs prepared on a competitive basis.

Changes of Pitch.—When a pitch closer than 6 inches is required it is frequently made 4 inches or 3 inches, so that consecutive stretches of riveting will work out at even feet, or at even feet and simple fractions thereof. Even fractions, such as ¼, ⅓, and ½, are particularly advantageous in the flanges or main angles of girders, because the transition from a wider to a closer pitch can be made very easily when the rivets are ranged at 2, 3, or 4 per foot run, corresponding with pitches of 6 inches, 4 inches, and 3 inches respectively.

Minimum Pitch.—Pitches less than 3 inches are exceedingly rare, and should not be adopted in structural work if they can be avoided, as they cut up the plates too much. A closer pitch can often be avoided by the use of a larger rivet, say ⅞ inch instead of ¾ inch diameter, or by the addition of other rows of rivets, arranged zigzag or staggered. Under no circumstances whatever should rivets be ranged at a closer pitch than three times the diameter of the rivet.

Summary of Rules as to Pitch.—Whether in pillars or girders the maximum pitch should not exceed sixteen times the thickness of the thinnest plate through which the rivet passes, or 6 inches, whichever is the lesser; and the minimum pitch should not be less than three times the diameter of the rivet, or 3 inches, whichever is the greater. In practice these rules will in general mean that the pitch of rivets should not be greater than 6 inches nor less than 3 inches.

Limitation of Rules.—It should be borne in mind that these practical rules are intended to apply only to buildings and similar structures. In bridge work 4-inch pitch in the compression flange, and 5-inch pitch in the tension flange is a very old rule, but in the compound girders of buildings, the pitch is usually the same in both flanges, and such a girder has certain practical advantages in facility and simplicity of design, construction, and erection.

Cross Pitch or Rivet Spacing.—The position of rivet holes in rolled

sections is now more or less unofficially standardized. The standard spacings represent a compromise between diverse requirements. The space available for rivets is shown by *a* in Fig. 258, and the centre of the available space is shown by the intersection of the diagonal lines.

Fig. 258 shows that the rivets are usually placed in the centre of the *available space*, but for a section of given overall dimensions, the spacing is not altered for every change in the thickness of the material.

For example, the *back gauge* for a 4-inch by 4-inch angle is just the same whether that angle is ⅜ inch thick or ⅝ inch thick. In this case it will be found that the centre line of the rivet only coincides with the centre of the available space when the angle is ½ inch thick, *i.e.* the back gauge = ½ inch + ½ of 3½ inches = 2¼ inches.

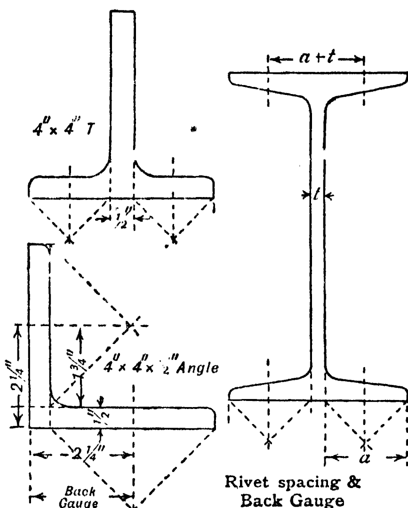


FIG. 258.

Generally speaking, rivet spacings or cross pitches are worked to the nearest quarter of an inch, and lesser differences are ignored.

RIVETING

Arrangement of Rivets.—All rivets should be arranged in such positions that both ends can be easily got at during construction. For example, taking the case of the compound girder in Fig. 259, any rivets which might be shown on the line 2 and 3 would be inaccessible from the inside, and could not be driven, except at the extreme ends of the girder.

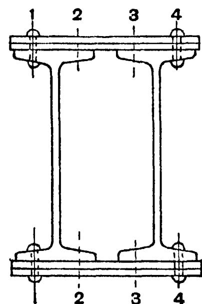


FIG. 259.—Riveting of Compound Girders.

Minimum Size of Flat Bars.—On account of the danger of corrosion and to establish the necessary balance between bearing stress and shearing stress, the minimum sizes of single bars should be 2½ inches by ⅜ inch approximately.

Margin and Width of Bars.—The distance from the edge of a plate or bar to the edge of the rivet hole is called the *margin.* The distance from the edge of the plate to the centre of the rivet is called the *inset* (see Fig. 260). The hole to take a ¾-inch rivet may have a diameter $\frac{1}{16}$ larger, *i.e.* $\frac{13}{16}$ inch. The margin of bar or plate should never be less than the diameter of the rivet hole. It

therefore follows that the minimum width of a bar should never be less than three times the diameter of the rivet hole. As we are not

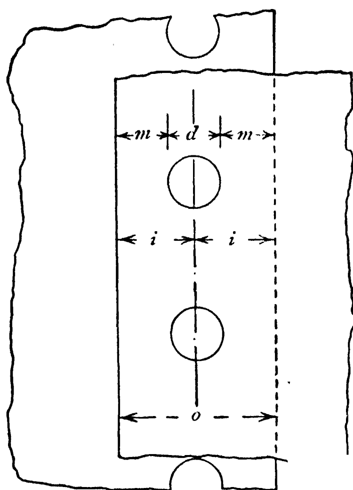


FIG. 260.—Insets and Margins for Lap Joints.

d = Diameter of rivets.
i = Inset.
m = Margin = d.
o = Overlap.

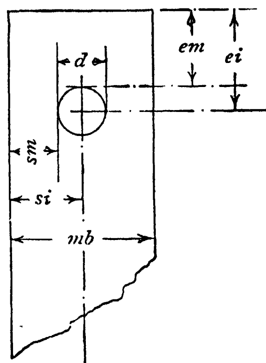


FIG. 261.—Diagram showing Insets and Margins for Flat Bars.

mb = Minimum breadth = $3d$.
d = Diameter of rivet.
ei = End inset = $2d$.
em = End margin = $1.5d$.
si = Side inset = $1.5d$.
sm = Side margin = d.

dealing with rivets less than $\frac{3}{4}$ inch diameter, it follows that the minimum width of bar should never be less than three times $\frac{13}{16}$ inch, *i.e.* $2\frac{7}{16}$ inches, or, in round figures, say $2\frac{1}{2}$ inches (see Fig. 261).

Rivet Holes.—The holes for riveting are best when drilled through the various thicknesses in one operation, so that the hole is quite smooth and true throughout. This procedure is usually adopted in heavy work, and in good class work generally.

Punching the holes is not to be recommended where the material is thick, as it tends to injure the plate. Sometimes holes are punched out $\frac{1}{4}$ inch less than the required size, and then drilled out to the final diameter, but the injured metal may extend too far to be removed by the subsequent drilling.

Size of Rivet Holes.—The rivet hole is usually made about $\frac{1}{32}$ inch to $\frac{1}{16}$ inch larger in diameter than the rivet, so that the latter can be easily inserted in the hole, when the shank is expanded by the heat. There is at present a certain amount of controversy and diversity of opinion as to whether the hole or the diameter of the rivet shank should be taken as the standard dimension. Some engineers are of opinion that it is most desirable that the hole should be the standard dimension, the allowance being made on the rivets.

Contractile Force of Rivets.—When rivets cool down they shrink and grip the plates together with a force which depends upon the difference between the initial and final temperatures, the cross-sectional area of the rivet, and the elastic properties of the steel.

Machine Riveting.—Machine riveting is more effective than hand riveting, for the mechanical pressure holds the plates closer together, and compresses the shank of the rivet so that it thoroughly fills up the rivet hole. The superiority of machine riveting is strikingly shown when rivets have to be taken out. After the head is cut off, a hand-clenched rivet may be easily driven out, but a machine-clenched rivet must, as a rule, be drilled out.

Identification of Machine Riveting.—Rivets clenched by machines can generally be distinguished from those done by hand; the latter are covered with marks caused by the shifting of the tool during riveting; while on a machine-riveted head there is generally a slight ridge round the base of the head, or else there is a slight burr like the peak of a jockey's cap, caused by the die having caught the rivet a little out of centre.

Inspection of Riveting.—All riveting should be carefully inspected, but the inspection of hand riveting should be very close, and the rivets should be sounded with a small hammer in order to detect loose or bad ones.

Single Rivets at Joints.—Joints containing a single rivet, as in some roof trusses, should be avoided if possible, because if the one rivet should be faulty there is no other rivet in reserve; and besides, if there is only one rivet in a bar, it is difficult to ensure that the bars to be joined will be held in the exact position, to obtain a straight rivet, free from cranking. Where there are two or more rivets at a joint, a bolt or a drift can always be put through one rivet hole, to keep the bars in position till the first rivet is closed.

Riveting in Situ.—Rivets which are driven in at the workshop are called *shop rivets*. Rivets which are driven in on the site for the purpose of connecting up the beams, pillars, and roof trusses are referred to as *field rivets* or *site rivets*. This process of driving such connecting rivets is spoken of as *riveting in situ*, which may either be done by hand or by portable riveting machines.

Riveting in Situ should be Specified.—Building owners should insist upon having steel-framed buildings riveted together, and architects should specify that the pillars and beams should be riveted together *in situ*. It should be remembered that unless the work is so specified, the endeavour to reduce the initial cost and prepare the lowest tender may lead to the cutting of prices down to below the minimum necessary for really good work. When there are no restrictions as to loads, stresses, and the quality of workmanship, it is unreasonable to expect that the strongest design will be accompanied by the lowest tender, and it is probable that the best firms and the best work will be excluded.

Riveted Joints.—Sometimes the strength of beams or pillars may be reduced by as much as 50 per cent by reason of badly designed joints. In checking designs of steelwork structures it is a safe rule to examine the joints first, for it is there that one will be most likely to find evidence

of negligence. Many structures have their main members carefully proportioned, except at the joints. This is particularly noticeable in the cranked girders and the jointed stringers of external iron stairs.

Riveted *v.* Bolted Joints.—Riveting, whether by machine or hand, holds the plates or members together much more firmly than bolts could do. In fact, riveted work is sometimes referred to as *fast work*, while bolted work is referred to as *loose work*.

Bolt Ends to be Riveted over or Burred.—In a few cramped positions, it is sometimes impracticable to provide the space necessary for driving a rivet in. Where bolts are used, they should extend through the full thickness of the nut or nuts attached thereto. The nuts should in all cases be so secured as to avoid risk of their becoming loose. The method usual in structural work is either to burr over the end of the bolt, or to hammer down the end of the bolt so that a slight rivet head is formed. In some cases the thread of the bolt is *upset* with a hammer and chisel. Cold riveting is probably the best, but the success of that process depends upon the bolt being of just the right length to form a neat, slight rivet head where it emerges from the nut.

It is no use attempting to draw bolts up too tight, as there is always the risk of injuring or stripping the thread. This risk is all the greater when workmen stick the spanner into a piece of piping to increase the leverage.

CHAPTER XIII

STEEL SKELETON BUILDINGS

By E. Fiander Etchells, Hon.A.R.I.B.A., A.M.Inst.C.E., A.M.I.Mech.E.

The details of the various parts of the steel skeleton have been discussed in the previous chapter, under the heading of beams, pillars, riveting, etc. This chapter deals with the assemblage of the various parts in the complete skeleton, and discusses questions relative to the design of the skeleton as a whole.

Definitions and Classification

Skeleton Defined.—The essential feature of a *skeleton* is that it is a framework of beams and pillars, with or without diagonal or other bracing.

A framework to support the external enclosures of a building is called an *external skeleton.*

A framework to support the floor loads in the interior of a building is called an *internal skeleton.*

The skeleton of a building may be either internal or external or both.

There are many types, and whether any particular type is such that it could be sanctioned under this or that Act or Byelaw is a question of legal and local interest, which is outside the scope of these notes.

Fig. 262 illustrates the assemblage of the various parts in a typical skeleton building.

Principal Types.—The four leading types of skeleton framework are the following:

(A) *External Skeleton.*—A skeleton framework to support the external enclosures of the building (see Fig. 263). This type is sometimes referred to as *shell construction.*

(B) *Internal Skeleton.*—A skeleton framework designed to support the loads in the interior of the building (see Fig. 264).

(C) *Intermediate Type: Complete Internal and Partial External Skeleton.*—A skeleton framework built between party walls, and designed to support all loads except those supported by the aforesaid party walls (see Fig. 265).

(D) *Combined External and Internal Skeleton.*—A skeleton framework designed to support all loads, including the weight of all the enclosing walls, and any pressures on such walls. This type is sometimes referred to as *cage construction* (see Fig. 266). (Also see Fig. 262.)

Factors affecting the Type or the Details of Skeleton.—The preceding system of classification is based upon the structural purpose of the skeleton, and not upon its proportions, or its stiffness, or the method of protection, if any. The effect of some of these factors is indicated in the following paragraphs.

Narrow Buildings.—If the building is so narrow that the floor beams may span from wall to wall, pillars in the central or interior portions of the building may not be necessary.

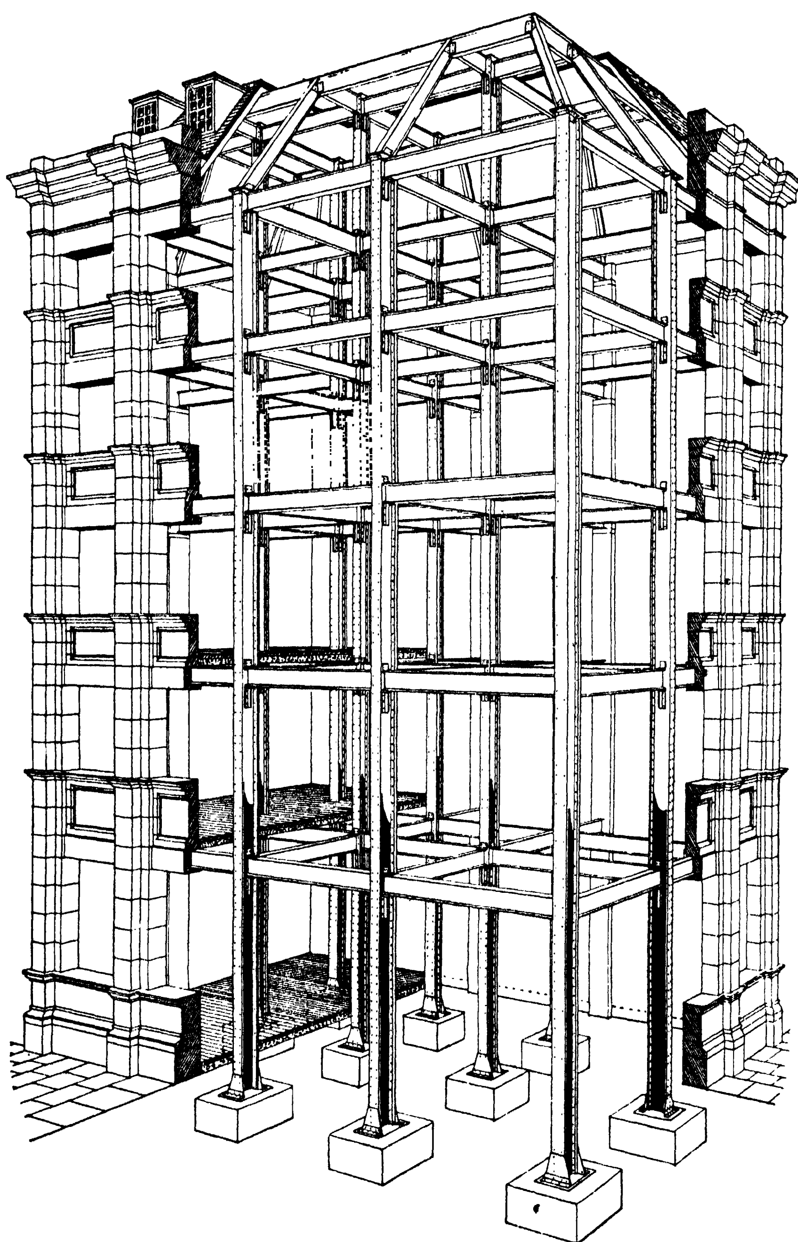


FIG. 262.—Diagram showing the Assemblage of the various Parts of the Skeleton.

Wide Buildings.—If the building is so wide that intermediate supports

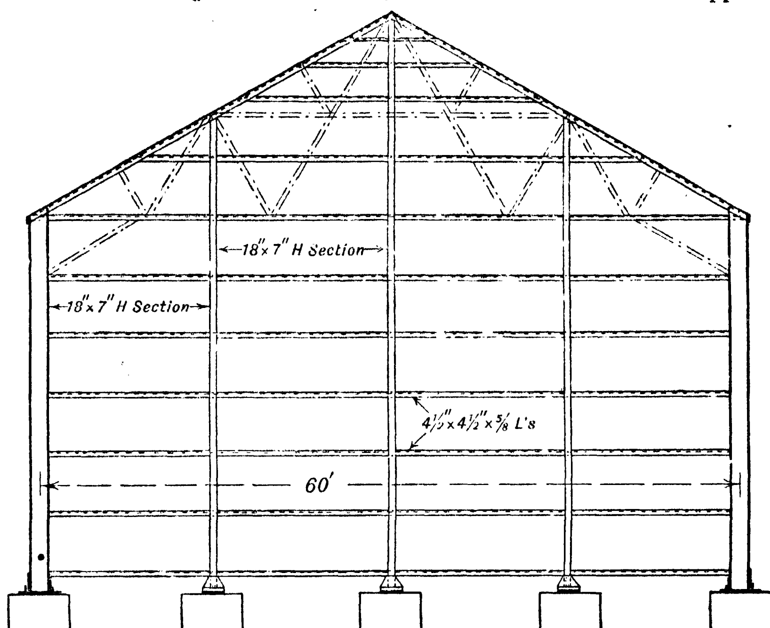


FIG. 263.—End Framing of External Skeleton (Shell Construction).

for the floor beams become necessary, then such floor beams, together with the pillars in the interior of the building, will constitute an internal skeleton. The necessity for an internal skeleton arises from the width of the building and not from its height.

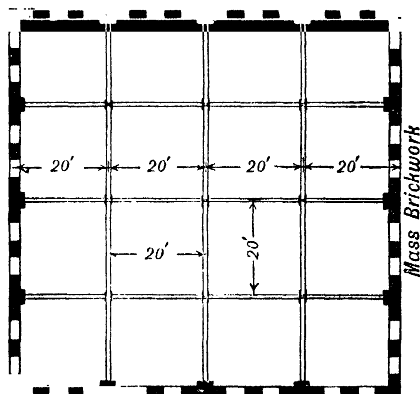


FIG. 264.—Sectional Plan of Internal Skeleton

High Buildings. — The height of the building or the number of stories is not essential to our classification of skeleton types. Local Acts may limit the height of buildings to suit local conditions, but a difference of height does not, as such, constitute any difference of skeleton type. For example, a building may be of cage construction, whether its height be two or twenty stories.

Wind Bracing.—The skeleton may be braced in various ways to

resist the wind pressure, or the building may be so low and the stanchions may be so stiff that special wind bracing may not be necessary. The presence or absence of wind bracing does not alter the classification of types set out above.

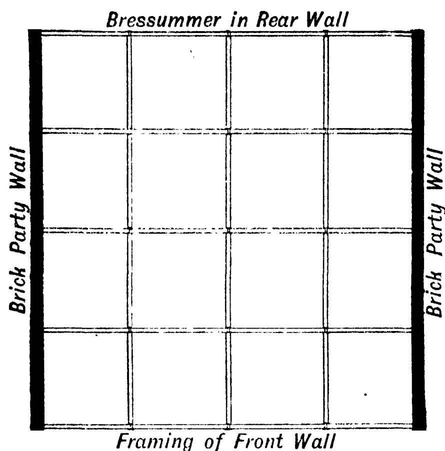


FIG. 265.—Complete Internal and Partial External Skeleton.

Protection of Steelwork.—The steel skeleton may be naked or it may be fleshed with brickwork, and clothed with masonry or other materials. These extraneous differences do not alter the type of skeleton, but they have a very marked influence on the details of the external skeleton.

Various Forms of Enclosures and their Influence Skeleton. — The properties and qualities of these various materials are discussed in Part III. The following notes are only given to show how the varidus materials affect the design of the skeleton of the building.

Corrugated Iron Sheets.—When a corrugated iron building has no internal lining the whole of the framing is usually of steelwork. • The sheets are secured to the purlins and side rails by means of hook bolts. Curved washer plates will be necessary to reduce the chances of rain working through at the bolt hole.

Plain Concrete.—When the enclosures are of plain concrete, the whole of the framing should be of steelwork. Such steelwork should not be painted or oiled, but it should be scraped and brushed to remove all loose rust. The concrete should be packed, rammed, or tamped, till it is as dense as possible, and should be in close and intimate contact with the clean and naked steel.

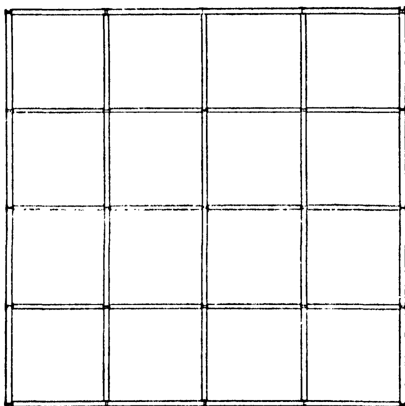


FIG. 266.—Sectional Plan (Cage Construction).

Reinforced Concrete.—The amount of concrete in the enclosures may be reduced by the addition of steel in such a manner as to constitute reinforced concrete panels. The reinforcing bars are not considered as an integrant part of the

skeleton, although they form an essential part of the fabric of the enclosure.

Concrete Blocks : Brickwork.—When the enclosures are of concrete blocks or of brickwork, the joints between the blocks or bricks and the steelwork should be well and thoroughly flushed with good stiff cement mortar or grout. Blocks of coke breeze, cinder concrete, ash concrete, furnace slag, or plaster of Paris, and similar materials are objectionable in contact with metal, but if necessity compels their use, extra care should be taken to have wider joints between the steelwork and the blocks, so that a good stiff paste or grout of cement mortar can be packed between the steelwork and such blocks.

Reinforced Brickwork.—This form of construction is somewhat unusual in skeleton buildings, as the pillars and beams are generally sufficiently close to enable the panels of brickwork to be carried safely without reinforcement.

Plaster.—When the enclosures are of plaster slabs or plaster moulded *in situ*, it is customary to introduce a certain amount of subsidiary wooden framing between the main members of the steel skeleton, as plaster is relatively weaker than concrete, and cannot be carried across such wide spans. Wood is usually adopted because it gives a good nail-hold for the plaster slabs, and because of the ease with which wooden members can be cut off to correct sizes, and joined up with the wooden framing of the doors and windows. Sometimes a certain amount of intermediate framing is saved by reinforcing the plaster by a metallic mesh; but this is to be deprecated. Most, if not all, plasters have a very corrosive action on steelwork.

Matched Board, Asbestos Sheets, Cement Slabs, Uralite, Poilite, and Similar Materials.—When corrugated iron buildings are lined internally with any of the above materials, it is essential to introduce a certain amount of subsidiary wooden framing to take the nails or screws which hold the internal enclosures in position. When such subsidiary wooden framing has been introduced it can be utilised to support the external enclosures also. In such cases some or all of the steel side rails and steel purlins can be omitted. It is, however, desirable to retain the eaves joist in steelwork, and also such other steel rails and purlins as may be necessary to ensure the stability of the steel skeleton, independently of any adventitious support which may be derived from the proximity of the wooden members, whose primary function is to support the enclosures. Under no circumstances should the eaves joist be omitted, as this joist will afford the best metallic tie between the tops of all the pillars round the building. The unsupported lengths of the pillars should always be calculated as the distance between metallic supports.

Examples of the Various Types

TYPE A. EXTERNAL SKELETON

Hay Sheds.—The simplest form of steel-framed buildings are probably the hay sheds and kindred structures used in various parts of the country.

They consist of four or more steel pillars of H-section, and a light corrugated iron roof. They have no side enclosures, and therefore require no side rails.

Dock Warehouses and Temporary Stores.—The next simplest are probably the one-story buildings, frequently used for dock warehouses and temporary stores. These buildings usually have steel side framing and roof trusses, constituting the external skeleton. The framing is covered externally with corrugated iron. In the case of dock warehouses or temporary stores, the floors are usually of concrete. The inside lining of the building is frequently omitted for the sake of economy.

Motor Garages.—Small steel-framed buildings covered with corrugated iron are sometimes used for motor garages. In this case a pit should always be constructed, so as to give easy access to the underside of the car for examination of the mechanism. Floor boards should be provided to cover the pit when not in use.

Engineering and other Industrial Workshops.—Large steel-framed buildings of one story in height are sometimes used for engineering and other industrial workshops. In these cases much of the corrugated iron gives place to glass. Buildings of this character can be extended in any direction, and the necessary light can be obtained by a glazed roof. If such a building be extended on all four sides, then the pillars and other framing of the external skeleton of the original building will become part of the internal skeleton of the extended building. The original external sheeting may be removed, or it may be used as an internal partition between two different departments of the works. If there is a possibility of the extension of such a building at a later date, coupled with the possibility of the removal of any side rails between the pillars, then the pillars from the commencement should be made stout enough to resist the estimated future loads without assistance from the bracing. This may slightly increase the first cost, but it will greatly decrease the cost of the extensions, as the original pillars will be sufficient to carry the extra load. The original pillars will get an additional load from the added roofs or cranes (if any), and a lesser proportion of the wind pressure on the side enclosures.

Aerodrome Buildings.—Recent development in aviation has evoked a corresponding development in structural work ; and we now have steel-framed structures specially constructed for housing aeroplanes and airships. These aerodrome buildings fall into two distinct classes.

Hangars for Aeroplanes.—Although the French word *hangar* is more usually applied to open sheds having no side enclosures, yet hangars for aeroplanes are almost always fully enclosed on all sides with wooden boarding or corrugated iron.

Airship Sheds.—Buildings for housing airships are usually light shells of corrugated iron on steel framing. On account of the absence of floors inside and on account of their great height, extensive bracing is necessary to resist the wind pressure on the vertical enclosure. By putting the side framing on the outside of the building, the span of the roof truss is greatly reduced, and there are not so many sharp edges of framing to tear the fabric of the envelope.

Mission Halls and Temporary Iron Churches.—Corrugated iron buildings are frequently used for mission halls and temporary iron churches. In these cases there is usually 6 inches of impervious concrete over the whole site of the building, and the floor boards, or floor joists and floor boards, may be laid over this concrete. The steel framing is usually lined with incombustible materials, such as cement and asbestos panels or sheets. In some country districts tongued and grooved match boarding may be used as internal lining. In the Metropolitan area the lining (if any) should be of incombustible materials.

Exhibition Buildings.—Steel skeleton construction is very largely used for exhibition buildings. In these cases the skeleton is usually fleshed with concrete or decorative plaster, or with a combination of both materials. For temporary exhibition buildings, erected for a few weeks in the summer, much of the work is bolted instead of being riveted. On the other hand, in many of the large cities there are permanent exhibitions. In these cases the skeleton is a riveted structure. The enclosures of both classes of exhibition buildings are usually of plaster or similar materials. The architectural treatment is superficial, and depends upon a skilful arrangement of woodwork and canvas, faced with plaster, which is known as *stick-and-rag* work, permitting the apparent architectural style of the building to be changed without appreciable change in the skeleton.

Cinema Theatres.—Cinema theatres are constructed with any of the four types of skeletons enumerated. Many are built with a steel external skeleton, fleshed with various combinations of brickwork, concrete, and plaster, and are finished after the style of exhibition buildings

TYPE B. INTERNAL SKELETON

In this type the external walls are usually of brickwork, or of brick and stone of the thickness necessary to comply with the local Acts, and to sustain the loads and pressures coming upon them. The internal skeleton is then designed to carry all the loads of the interior.

Such buildings should have the steelwork protected from the action of fire, because the stability of the walls partially depends upon the stiffness of the floors and the rigidity of the steelwork. The internal skeleton should also be adequate to provide the lateral rigidity which is obtained in "all-brick" buildings, by the provision of cross walls and massive piers.

Type B is a favourite one for new office blocks, warehouses, and similar buildings, in cases where there are existing party walls on either flank, and where the architectural treatment of the front and rear elevations is designed so as to be in harmony with the adjoining premises, which are frequently of mass brickwork or masonry.

TYPE C. INTERMEDIATE TYPE OF SKELETON

Buildings of this type are usually adopted when suitable party walls of brickwork are available on both flanks, but where such party walls or other return walls are too far apart to support properly the walls

in the front and rear elevations. The type is also sometimes suitable for new buildings on crowded sites and in narrow streets. The narrowness of the street may shut out much of the light, but the greater amount of window area statically possible in steel-framed walls will improve the natural lighting of the rooms to a certain extent.

TYPE D. CAGE CONSTRUCTION

This type is adopted for large buildings where existing party walls are not available or are unsuitable for the new purpose. Some buildings are so situated that they abut up two, three, or even four streets. In such cases cage construction will be found very suitable. Cage construction will also reduce the amount of brickwork necessary in the enclosing walls, and will enable a greater area of the elevation to be occupied by window openings, and thus improve the lighting of the interior portions of the building.

ADVANTAGES OF SKELETON CONSTRUCTION

Temporary Buildings.—The advantages of steel framing for temporary buildings are :—

(*a*) Cheapness.
(*b*) Saving in time of erection.
(*c*) Facility of removal.
(*d*) Facility of re-erection on another site.

Permanent Buildings.—The principal advantages of steel skeleton construction for large permanent buildings as compared with brickwork are stated below :

Saving of Brickwork.—The saving of brickwork is illustrated by Figs. 267 and 268, which show a vertical section of a brick-built warehouse wall, compared with the panels of brickwork set between steel framing.

Saving of Floor Space.—In crowded city sites the percentage of extra floor space saved by the erection of thinner walls is appreciable. Suppose a building measures 60 feet by 60 feet from outside to outside ; then for 1 foot of thickness saved in the thickness of the wall we have an area of 236 square feet added to the available floor space in each story. The percentage of floor space gained will vary with every case, but it is always appreciable. The saving of floor space by the use of steel pillars in lieu of brick piers is also shown by Figs. 269 and 270.

Fig. 271 shows the floor area occupied by pillars of different materials, but of equal height, and each capable of safely supporting an equal load, viz. 200 tons.

Reduction of Load on Foundations.—Figs. 269 to 271 also show that the adoption of steel framework will greatly decrease the amount of dead load necessary to support any given superimposed or live load. This will reduce the load on the foundations.

Increased Strength, Stiffness, and Stability.—Skeleton construction generally, and cage construction in particular, render a building more rigid and less liable to distortion and unequal settlement than the dis-

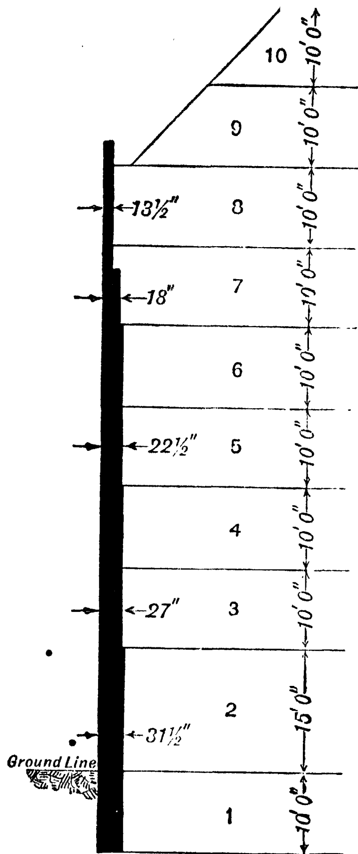


FIG. 267.—Self-supporting Brick Wall for a Building of the Warehouse Class.

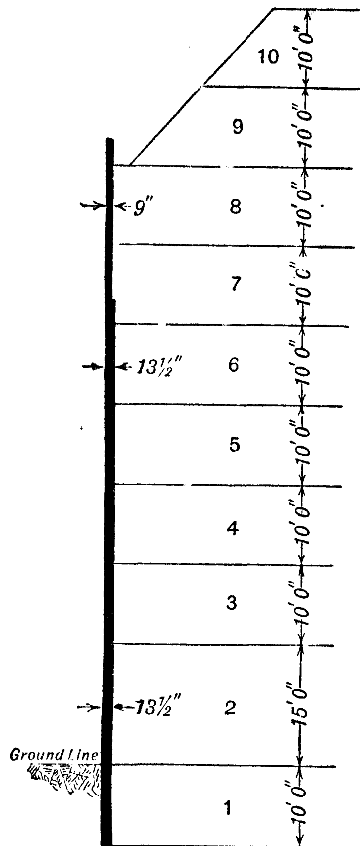


FIG. 268.—Panels of Brickwork in a Steel Skeleton Building of the Warehouse Class.

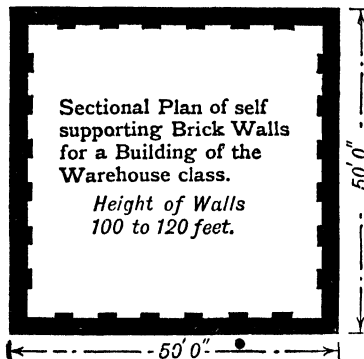


FIG. 269.—Ratio of Plan Area of Walls to Area of Building.

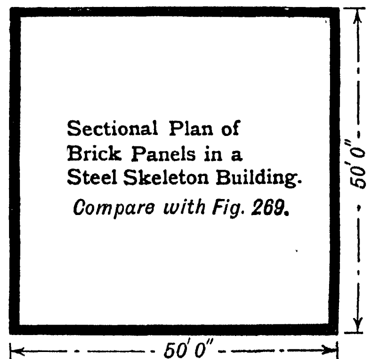
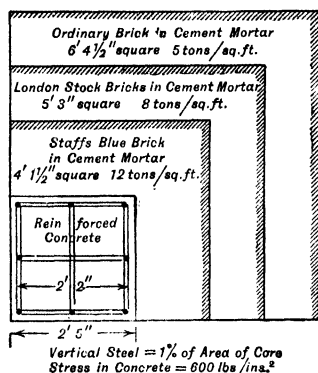


FIG. 270.—Ratio of Plan Area of Walls to Area of Building.

jointed or discontinuous association of steelwork, brickwork, and timber found in the older types of building.

Greater Freedom from Vibration.—The cage buildings are less liable to chattering and vibrations due to fast and heavy road traffic than is the case with the older types of building, particularly those of light construction.



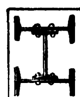




FIG. 271.—Diagram showing Relative Sizes of Various Pillars to carry Approximately Equal Loads.

Adaptability for Awkward Sites.—Skeleton construction is more adaptable to awkward sites and elevations than massive brickwork construction. A steel frame with light brick panels is also advantageous when a building is set back from story to story to meet the necessity of providing air and light to adjoining sites.

Better Lighting of Cage Buildings.—As the brick walls are not necessary as load carriers, the amount of window space can be increased. Indeed, where local Acts or Byelaws permit, some steel-framed factories have glass enclosures extending from pillar to pillar.

Saving in Time of Erection.—The constructional steelwork can be manufactured while the site is being prepared. As soon as the framework is erected, the enclosing walls can be proceeded with simultaneously on each floor.

Facility of Rearrangement of Rooms and Partitions at any Future Time.—Where the rooms are merely constituted by the erection of light incombustible partitions, the partitions can always be rearranged without seriously affecting the skeleton framing.

DESIGN AND CONSTRUCTION

Wind Pressure and Wind Bracing.—The following points are of importance in connexion with the design and construction of steel skeleton buildings.

Gable-end Framing.—Gable construction to support corrugated sheeting or reinforced concrete panels should be designed to resist safely the wind pressure, in accordance with the requirements of the local Acts or Byelaws. In the absence of legislative requirements, and in such geographical conditions as are found in the Metropolitan area, the wind pressure on gable framing and side enclosures of corrugated-iron buildings may be taken as a uniformly distributed horizontal pressure of 20 lb. per square foot of vertical surface, normal to the direction of the wind.

Effect of Height and Area on Intensity of Wind Pressure.—Wind pressure must be taken at a higher figure as the height above the surface of the ground increases, and on relatively smaller areas. These variations are due to the fact that wind pressures are reduced near the ground, and that the highest pressures are recorded in gusts.

London Buildings.—Buildings erected under the London County Council (General Powers) Act, 1909, must be so designed as to resist safely a wind pressure in any horizontal direction of not less than 30 lb. per square foot of the *upper two-thirds of the surface* of such buildings exposed to wind pressure. Buildings erected under the London County Council regulations of 1914 must be so designed as to resist safely a wind pressure in any horizontal direction of not less than 20 lb. per square foot *of the whole projected surface* normal to the direction of the wind. The total pressure is the same in both cases, but the centre of pressure is lower in the 1914 method.

Wind Bracing.—The rules for guidance in respect of steel skeleton buildings, as issued by the District Surveyors' Association (London) state that: "The buildings should be sufficiently braced to ensure that there shall be no material deflection in the pillars," and that "the stresses on any internal framing should be calculated as though the building were a braced cantilever set on end."

Provision for Expansion and Contraction.—Formerly in buildings with ordinary brick walls and some internal steel framing, much of the steelwork was merely bolted together, and there was a free space left at the ends of the girders to allow for expansion and contraction due to changes of temperature. Sometimes slotted holes were used at girder ends. Now, with the advent of greater knowledge of the behaviour of steel-frame buildings, the more extended use of riveting machines and the introduction of thinner walls supported on bressummers, riveted work is fast supplanting bolted work. Some of the largest steel-frame buildings in the kingdom are riveted together throughout, with scarcely a bolt anywhere, except perhaps the foundation bolts or bolts in the grillages. The steel is of course partially protected from extremes of temperature by the stone, brick, or concrete casing; but there is no specific provision for expansion or contraction due to temperature changes in the steel framing.

Experience seems to show that when the nominal working stresses due to the dead and superimposed load is kept at about 7½ tons per square inch, there is sufficient margin to cover safely secondary stresses and the stresses ordinarily induced by changes of temperature. In the case of steel arches, however, special provision may require to be made for these induced stresses.

Prevention of Unequal Settlement.—Practical notes on rivets and riveting are given in Chapter XII. The following notes only deal with riveting as a means of preventing or reducing any inequality of settlement of the building. A building which has its beams and pillars riveted together is immeasurably stronger, stiffer, and more rigid than a steel-frame building which is merely bolted together. This greater stiffness and rigidity are advantageous, even in respect of the smaller details of a building, for the plastered walls and ceilings and door and window frames

are less likely to develop those defects which are indicative of irregular movement and unequal settlement of the skeleton framing.

All buildings must, in the course of time, settle down to a position of equilibrium on the natural foundations, but with a good substructure, well designed, and with a skeleton properly and adequately riveted together, this settlement should not be sufficient to mar the work of plasterer or joiner. The increased cost of maintenance should always be set off against any initial economy effected by the omission of site rivets and the substitution of bolts.

It should be borne in mind that the tendency to unequal settlement in a riveted structure may induce additional stresses in that structure, but there is ample evidence to show that a nominal working stress of not more than one-half of the stress at yield point provides ample margin for these secondary uncalculated and incalculable stresses.

The London County Council (General Powers) Act, 1909, requires that rivets shall be used where reasonably practicable. The term rivets here means *site rivets* as well as *shop rivets*. To apply the words of the Act only to those rivets which are driven in the workshop, and to use bolts for all other connexions is a direct infringement of the Act.

Preservation of the Steel Skeleton.—Steel rusts through and through, because in the first instance an oxide of iron is formed on the surface of the metal, and this layer of oxide gives up some of its oxygen to the iron underneath, and takes in a fresh supply from the air. Thus corrosion will continue its destructive work until what was once a sheet of steel becomes merely layers of rust.

Paint.—Paint is only a transient protection. It is sometimes stated that the paint is best which lasts the longest; but that statement ignores the important question of cost, which must be considered in selecting a paint. The economic efficiency of a paint is measured by the ratio of durability to cost or by the cost of maintenance per annum.

Concrete.—Speaking generally, the corrosion of steel is accelerated in the presence of hydrogen compounds (acids) and retarded in the presence of alkalies. Portland cement in setting liberates a large quantity of lime, which is a strong alkali, and will delay the corrosion of the steel. But some concretes are poorly made of porous materials. In such cases any percolating water will gradually dissolve and wash away the lime, and the embedded steel will be free to rust. Therefore, to protect steel against rust, concrete should be impervious, and be rammed until it is as dense as possible, and thus made practically water-tight and damp proof. Gravel concrete is less pervious than brick concrete, and has a higher crushing resistance. On the other hand, brick is a better fire resistant than gravel. Where brick is used in the making of concrete it should be well soaked, so that it will not absorb the moisture from the mortar, and an extra proportion of cement should be used to fill up the pores of the brick. Several inches of good dense impervious concrete interposed between the steel and the air will afford one of the best of preventives of rust, and at the same time will afford the usual protection from the effects of fire. The thicker the concrete the greater the protection against both rust and fire, if the concrete is applied so that it cannot crack or fall off. There are

many instances of the efficacy of impervious concrete as a preventive of corrosion. There is a great iron chain embedded in concrete round the base of the dome of St. Paul's Cathedral. When an opening was made in the concrete the iron was found to be unrusted even after two hundred years.

Porous Concretes.—The only cases recorded in which steel is said to have corroded when embedded in concrete are those where percolating water had been present, and where porous aggregates had been used. Coke breeze and cinder and similar concretes should be avoided, not only because of the risk from the contained sulphur, but also because such concretes are frequently porous.

Lime Mortar.—Lime mortars are porous, and should not be used in contact with metal.

Plaster of Paris.—The calcium sulphate, which is the principal constituent of plaster of Paris, is also objectionable in contact with metal.

Thickness of Protective Casing.—The minimum thickness of casings permitted under the London County Council (General Powers) Act, 1909, are shown by the following diagrams.

Fig. 272 shows the casing of a pillar of the external skeleton. Fig. 273 shows the casing of a pillar of the *internal* skeleton. Fig. 274 shows

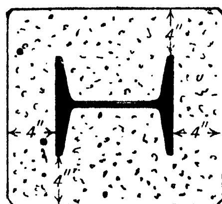


FIG. 272. — Protection of Pillars in the External Skeleton.

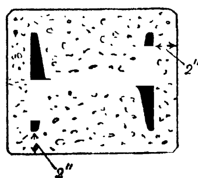


FIG. 273. — Protection of Pillars in the Internal Skeleton.

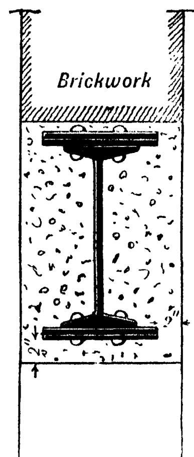


FIG. 274.—Protection of a Girder in the External Skeleton.

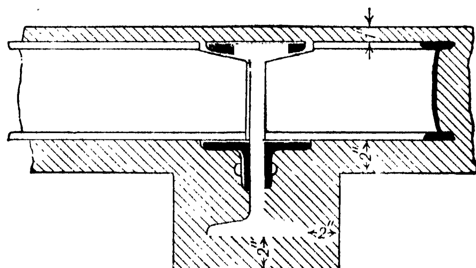


FIG. 275.—Protection of Girders of the Internal Skeleton.

the casing of a girder of the *external* skeleton. Fig. 275 shows the casing of the girders of the internal skeleton. The casing on the upper and lower surfaces of filler joists need only be one inch thick.

Unprotected Steel Structures.—The writer has taken layers of rust nearly $\frac{3}{8}$ inch thick from the flanges of main girders, and has seen web plates rusted right away from one main angle to the other. In both cases the girders were able to carry their normal load, owing to the initial provision of a safety factor, which was in excess of the stress requirements at the time the girders were erected.

It is not always economical or convenient to protect steelwork from the weather or from moisture or from corrosive fumes. In these cases it is usual to prolong the life of the structure by using thicker plates than would otherwise be necessary. Obviously the thicker the plate the longer it will withstand corrosion.

A structure designed for a stress of $7\frac{1}{2}$ tons per square inch would have a stress of 15 tons per square inch if 50 per cent of the original area had been converted into iron oxide or rust, for the cohesive strength of rust is negligible compared with the cohesive strength of steel. Thus by using thicker plates than is necessary for the stress requirements under the initial conditions, the conservation of the necessary margin of safety may be ensured, although a certain amount of corrosion may afterwards occur.

Efficiency of Design.—Economy is the product of many factors, and not merely the result of an exact balance between load and resistance to load. Economy is relative and depends upon the life of a building, and the length of the lease, and the solution of other problems beyond the scope of this work.

The question of structural efficiency is more simple. Material is cheaper than labour, and the adoption of a design in which the area of each member is worked out to a nicety may reduce the weight and increase the cost. The design which is structurally the most efficient is that which shows the highest ratio of ultimate load to total cost.

Unit of Plan.—The cost of construction and erection will generally be reduced by the adoption of a convenient unit of plan, and by conserving this unit throughout as far as the exigencies of the site will allow.

In Fig. 264 the unit of plan was 20 feet by 20 feet, but 16 feet by 16 feet is very common.

Design of Steel-Skeleton Buildings.—The following is an outline of procedure for adoption in the design of steel-skeleton buildings:

(1) Select the type of skeleton most suitable for the particular conditions.

(2) Draw up a plan of the building to suit the available site.

(3) Select the parts of the ground where the pillar loads may be concentrated.

(4) Build up the plans floor by floor, starting from the ground, till the roof is reached.

(5) In determining the exact sizes of structural members reverse this order. Start with the roof and work downwards.

(6) Take roof and floor slabs and then the embedded joists. Follow on with secondary beams; then the main beams or primary beams; then proceed with the pillars, and so on, till the foundations are reached.

CHAPTER XIV

REINFORCED CONCRETE, REINFORCED BRICKWORK, AND CONCRETE BLOCKS

By W. Noble Twelvetrees, M.I.Mech.E., M.Soc.Ing.Civ.

REINFORCED CONCRETE

General Principles

Definition.—Reinforced concrete is formed by the employment of concrete and steel in combination, each material being applied so that its distinctive properties are utilised to the best advantage.

The concrete is the only material visible in structural members of reinforced concrete, but considered separately is not able to perform the whole of the duty for which the members have been designed, its proportionate capacity varying considerably according to circumstances.

The steel bars, with rods or strips, reinforcing the concrete are embedded sufficiently for their protection from fire and corrosion, and are placed with special regard to the distribution of the stresses to which the concrete offers little, or no practical, resistance. Considered separately, the collection of units constituting the reinforcing system does not form a structural member, and unless tied together, or otherwise connected as sometimes is done for convenience of construction, the reinforcement is nothing but a number of loose bars and rods or strips. It is only when embedded and firmly held in their proper places by the surrounding concrete that the steel units become valuable and effective details of the structural member.

Thus it will be seen that reinforced concrete is something essentially different from a steel beam, a steel column, or a steel frame merely embedded or cased in concrete. Nevertheless, the casing of steelwork in concrete is advantageous in building construction for protecting the metal from heat and corrosive influences, although the materials so employed side by side do not constitute reinforced concrete.

To obviate the risk of misconception, it may here be pointed out that structural steel sections, such as T-bars and I-beams, are employed by some designers in conjunction with concrete in such manner as to form genuine reinforced concrete. Although large steel sections are less advantageous than thin steel bars from the theoretical standpoint, their

use as reinforcement may sometimes be attended with practical advantages which deserve consideration.

Principles of Beam Design.—The principles underlying reinforced concrete construction are best illustrated by the case of any member acting as a beam.

In a beam of plain concrete, the tensile resistance of which is about one-tenth of its compressive resistance, the permissible tensile stress imposes a limit on the compressive stress, and the neutral axis is consequently equidistant from the upper and lower surfaces of the concrete. Owing to the low tensile resistance of the concrete, nine-tenths of the compressive strength possessed by that material is absolutely wasted in the compression area of the beam. This point is illustrated diagrammatically in Fig. 276, where the shaded area above the neutral axis represents the proportionate strength of the concrete utilised in compression, the remainder being of no practical use. By inserting steel bars in the tension area of a plain concrete beam the full compressive resistance of the concrete can be developed, as illustrated in Fig. 277, where the amount

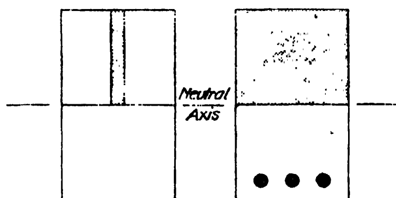


FIG. 276.

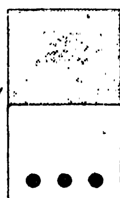


FIG. 277.

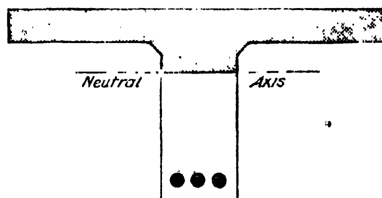


FIG. 278.

of steel added in the form of three bars is relatively small and inexpensive. A more economical arrangement is shown in Fig. 278, representing a T-shaped beam with a wide compression flange and thin web, the sectional area of concrete being the same as that in Fig. 277, but disposed more advantageously, and the beam develops far greater resistance to flexure without requiring larger quantities of the materials.

Although concrete possesses appreciable resistance to tension, this property is usually neglected in practical design, because the tenacity of the material is virtually destroyed at an elongation corresponding with the stress of about 5000 lb. per square inch in the steel, the result being the development of minute cracks, so small and so uniformly distributed as to be exceedingly difficult of detection, and which do not appear to be in any way detrimental in practical construction.

The theoretical economy of reinforced concrete in beams is indicated by the fact that for equal duty the cost of concrete in compression is only about three-fifths that of steel, and that for equal duty the cost of steel in tension is barely one-sixth that of concrete.

The practical economic advantage of reinforced concrete in beams varies with the relative dimensions of the compression and tension areas, and the proportion of steel employed. If the proportion of steel is heavy, the economy is reduced, and the same effect follows the adoption of steel

in the compression area, because in either case it is impossible to develop the full permissible stress in the steel.

Apart from any question of cost, however, reinforced concrete in beams possesses important practical recommendations. The resistance of the combination to fire and corrosion reduces insurance premiums, obviates the need for fire casing, and reduces maintenance charges to a minimum.

Principles of Column Design.—Reinforced concrete shows to less marked advantage in column construction, chiefly because it is not permissible to utilise the strength of the main reinforcement so fully as in beams. The working stress in the bars used as longitudinal reinforcement is usually limited to fifteen times the permissible compressive stress in the concrete, but steel employed as lateral or circumferential reinforcement can be stressed to the full permissible value and is most effective, not only bracing the longitudinal bars but also helping to restrain lateral expansion of the concrete under axial loads. Considère states the value of steel so applied to be 2.4 times that of steel used longitudinally, this estimate being approximately confirmed by the later investigations of Professor Talbot and others.

In reinforced concrete columns we have concrete and steel working together to withstand compressive stress due to axial loads, and steel in the form of lateral or circumferential ties restraining the lateral expansion of the concrete, thereby increasing the resistance of that material to axial compression. In the case of long columns and columns under non-axial loads, the longitudinal reinforcement is very effective in withstanding stresses due to flexure.

Although the steel cannot be utilised to such great economy as in the case of beams, the adoption of reinforced concrete columns carries with it the reduction of fire risks and maintenance charges, obviates the cost of fire casing, and conduces to increased strength and rigidity, owing to the monolithic connection between the columns and other reinforced concrete members of the structures wherein the columns are employed.

Web Reinforcement in Beams.—It is very important that adequate provision should be made in the form of suitable web reinforcement for resistance to diagonal tension in reinforced concrete beams, this secondary stress being the result of vertical shear and flexure. As the intensity of tension on diagonal planes cannot be determined, it is usually measured by the intensity of vertical, or horizontal, shearing stress. Some designers provide for a part of the diagonal tension to be taken by the concrete, but this is contrary to the rule that the tensile resistance of the concrete shall be neglected, and a wiser course is to provide sufficient reinforcement to withstand the whole of the diagonal tension, as computed in terms of vertical shear.

Web reinforcement is formed of hoop steel, thin round rods, or strips projecting from the bars of the main reinforcement, and sometimes by bending up the ends of main reinforcing bars. Some designers dispose the web members vertically, and others place them diagonally. All methods appear to be of approximately equal efficiency, the only essential consideration being the provision of sufficient steel properly disposed

and spaced at intervals which are not too great for protection of the concrete. A very effective arrangement is the combination of vertical loops or ties with the bent up ends of some or all of the main tension bars.

Reinforcement of Continuous Beams.—The practice of bending up the ends of main tension bars enables the designer to provide in a simple and effective manner for the negative tension which occurs between the supports and the points of contra-flexure in the upper part of continuous beams, and beams with fixed ends. The bars so bent up should be carried well over the supports to insure ample anchorage, and continuous action can be still better provided for by using bars long enough to extend over two or more spans of continuous beams. In cases where separate bars are used, the ends bent up and carried over the supports can be left of length sufficient to extend into adjoining spans, and so double the amount of reinforcement against negative tension.

The foregoing remarks apply equally to floor slabs, which are essentially broad and shallow beams. Continuous beams and slabs are sometimes unequally loaded; with the result that some panels are bent downward and others upward. Where conditions such as these are likely to occur, reinforcement near the top surface is as necessary as that near the bottom surface of the concrete.

Bond between Concrete and Steel.—Well authenticated tests show that the adhesion between concrete and steel ranges from about 200 lb. to 750 lb. per square inch of the surfaces in contact for ordinary round bars. Hence European designers generally consider the natural bond between the two materials as quite adequate. In the United States, the same practice is largely followed, but the employment of specially rolled bars with projecting ribs of various forms is very common. The object of such bars is to furnish a bond with the concrete independent of adhesion.

Uses of Reinforced Concrete in Building Construction.—Reinforced concrete has been largely employed in the construction of complete buildings, but is more generally used in constructing a frame, comprising columns, beams, floors, stairs, and sometimes roof, the whole enclosed by brick or stone walls carried by wall lintels and columns forming parts of the frame.

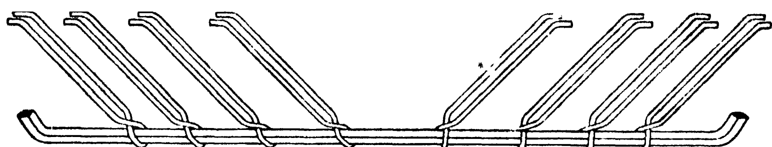
Among the individual structures and details to which reinforced concrete is applied in building construction are: foundation rafts, retaining walls, footings, column bases, columns, beams, floors, roofs, walls, stairways, balconies, strong rooms, and water tanks. Those who are familiar with the principles of ordinary building construction, and have mastered the design of reinforced beams and columns, will have no difficulty in dealing with the foregoing structural details.

An important matter, however, after the individual members for a structure have been designed, is to make provision for their connexion in the most secure and rigid manner possible, a task usually involving the filling up of angles by extending the head of columns, adding knee-braces and haunches, and applying suitable reinforcement to the connexions formed.

Systems of Reinforced Concrete

The principles governing reinforced concrete construction can be applied with the aid of suitable concrete and reinforcement in the form of ordinary steel bars, rods, and strip such as are obtainable in the open market. Many specialist firms, however, attach importance to the provision of reinforcement in special forms.

Summary of Principal Systems.—In the following notes the essential features of each system are briefly outlined, and illustrated where necessary. Several firms, in addition to those here mentioned, apply reinforced concrete to the construction of floors, the subject-matter of the present



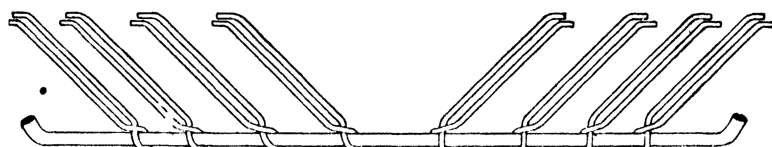


Fig. 279.—Stirrups for Square and Round Bars.
(British Reinforced Concrete System.)

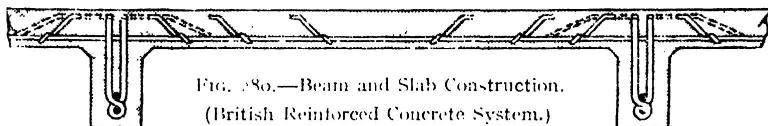
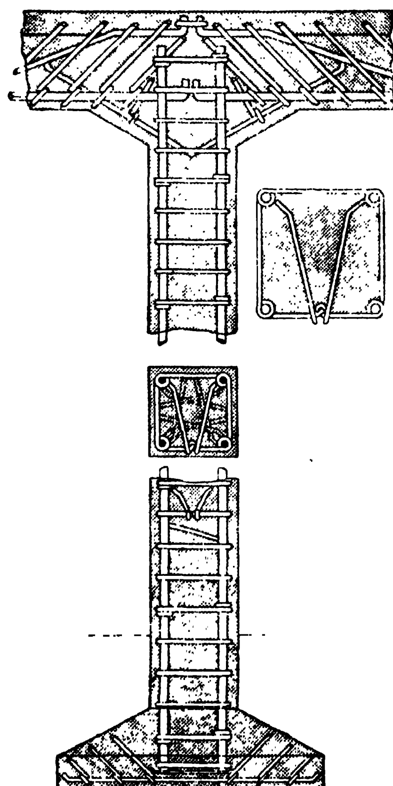
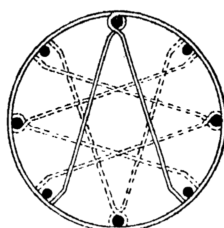


Fig. 280.—Beam and Slab Construction.
(British Reinforced Concrete System.)

section being restricted to systems intended for general application to building construction.

British Reinforced Concrete Engineering Co., Ltd.—Beams and slabs reinforced with round or square longitudinal bars, and web reinforcement of the form represented in Fig. 279 designed to grip the main bars tightly. The stirrups can be made of round rods or of strip as preferred, and it is recommended that they should be disposed at an angle of 45 degrees. Fig. 280 represents the application of the system to floor construction. Columns reinforced by four or more longitudinal bars with lateral bracing in the form of hoops are represented in Fig. 281. Every fourth hoop is of the type with coiled corners holding the bars in correct position, and intermediate hoops are of the other type illustrated. Fig. 282 shows the type of helical reinforcement adopted by the same firm for circular columns.





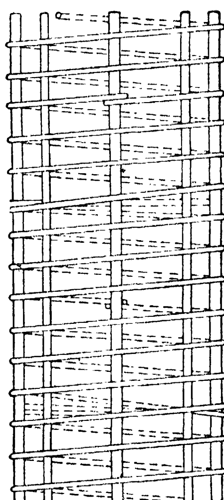


FIG. 281.—Column Construction.

FIG. 282.—Spiral Column Reinforcement.

(British Reinforced Concrete System.)

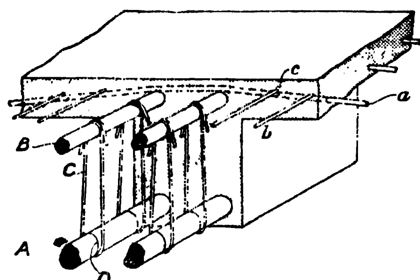


FIG. 283.—Beam Reinforcement.
(Coignet System.)

A = Main tension bars.
B = Main compression bars.
C = Web ties connecting bars of types A and B.
D = Annealed wire holding ties C in place.
a = Principal rods in slab.
b = Secondary rods in slab.
c = Annealed wire ties at intersection of rods *a* and *b*.

Edmond Coignet, Ltd.—Beams reinforced by round longitudinal bars at top and bottom, the two series being connected by web reinforcement consisting of ties formed of round rods and wired to the main bars. An alternative type of reinforcement consists in replacing the bottom bars and the web ties by a series of bars of different lengths, the ends of these being bent up at an angle of 45 degrees and hooked over the upper bar or bars. The straight parts of the bars provide resistance to tension, and the bent up parts resistance to web stresses. These two types of reinforcement are illustrated in Figs. 283 and 284. Slabs are reinforced similarly to beams, but in the case of slabs less than 6 inches thick the bars are placed only near the bottom of the concrete, and are bent up over the supports to act as web reinforcement. In every case the bars are arranged both

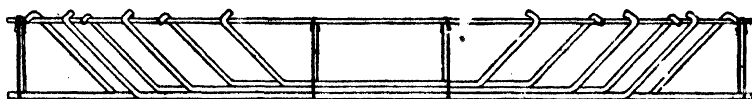
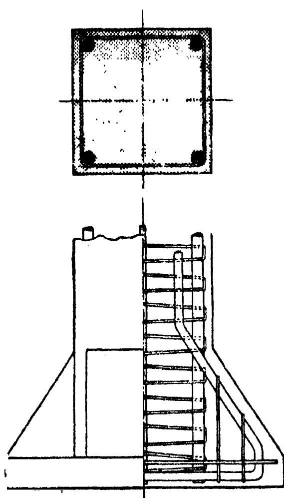


FIG. 284.—Alternative arrangement of Reinforcement. (Coignet System.)

longitudinally and transversely to the axis of the slab. Columns are reinforced by longitudinal bars braced laterally by horizontal or helical ties. The longitudinal bars are continued into the column base, as shown in Fig. 285. Wall panels are reinforced by a network



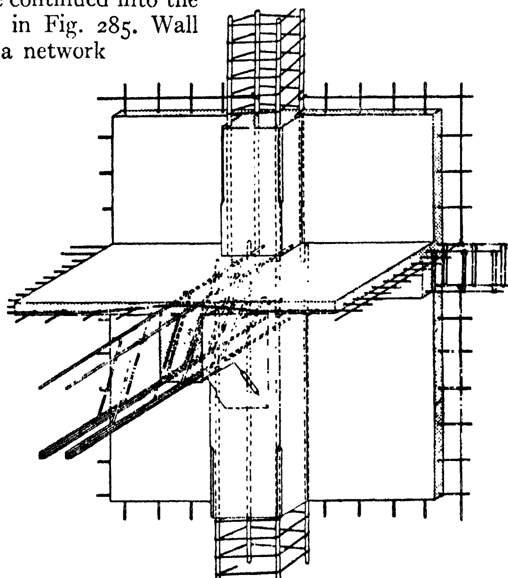


FIG. 285.—Column Construction. FIG. 286.—General application.

(Coignet System.)

of vertical and horizontal bars wired together and placed in the middle

of the wall. Fig. 286 illustrates the general application of the Coignet system.

The Considère Construction Co., Ltd.—Ordinary beams reinforced by longitudinal round bars in tension, or in tension and compression, web reinforcement formed by bending up some of the tension bars towards the supports, and by the provision of stirrups of round rod passing under the tension bars and anchored in the compression area of the beam, or passed over the compression reinforcement where the latter is employed. Continuous beams are reinforced as shown in Fig. 287. The upper fibres above intermediate supports are heavily armoured, and spiral coils are introduced in the lower fibres to withstand compression. Columns are reinforced by longitudinal round bars and lateral bracing in the form of helical winding.

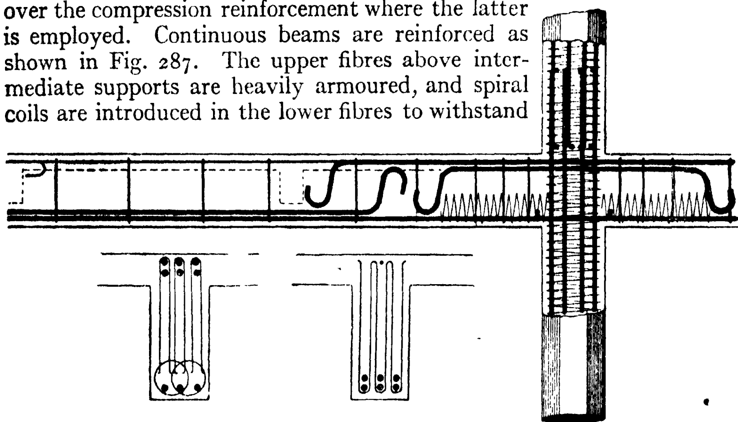


FIG. 287.—Beam and Column Construction. (Considère System.)

Indented Bar and Concrete Engineering Co., Ltd.—The specialty of this firm is a patented bar, made both square and round, as represented in Fig. 288, and of either high-tension or mild steel as required, but high-tension steel is recommended by the makers. The corrugations on the surface of the bar are designed to furnish a reliable mechanical bond, independent of the natural adhesion between the concrete and the steel. Beams are reinforced by longitudinal bars for resistance to tension, and compression where desirable, web reinforcement being usually formed by bending up the ends of tension bars of different lengths, as represented in Fig. 289. Slabs similarly treated; wall panels reinforced by a network of vertical and horizontal bars. Columns reinforced by



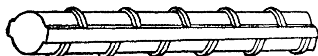


FIG. 288.—Indented Bars.

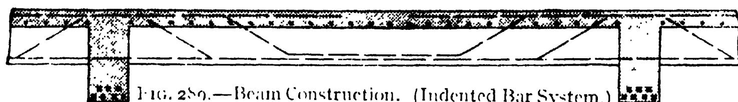


FIG. 289.—Beam Construction. (Indented Bar System.)

four or more longitudinal bars braced with lateral ties of soft iron or steel wire at suitable intervals apart.

L. G. Mouchel and Partners (Mouchel-Hennebique System).—Beams reinforced with longitudinal round bars in tension, or in tension and compression, web reinforcement formed partly by some of the tension bars

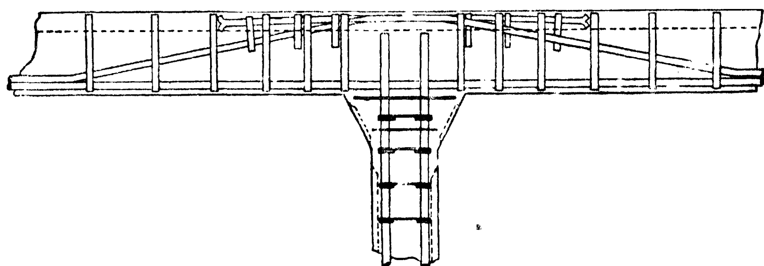


FIG. 290.—Continuous Beam and Columns. (Mouchel-Hennebique System.)

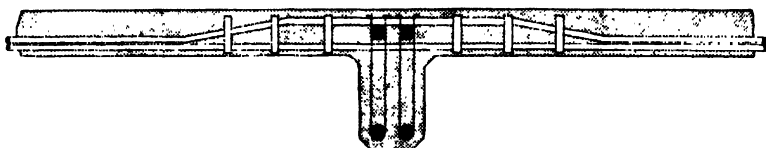


FIG. 291.—Beam and Slab Construction. (Mouchel-Hennebique System.)

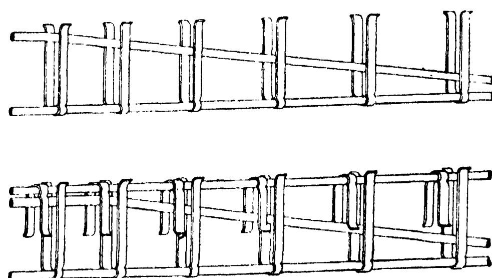


FIG. 292.—Main Bars and Stirrups.

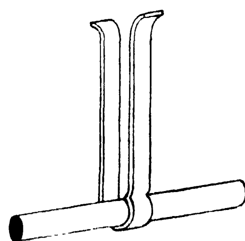


FIG. 293.—Stirrup clipped on Bar.

(Mouchel-Hennebique System.)

bent up towards the supports, and partly by vertical stirrups consisting of steel strip bent to U-shape passing under the bars and anchored in the compression area by means of the turned-over ends. Slabs are similarly reinforced, but without stirrups in cases where the thickness is small. Fig. 290 shows the reinforcement of a continuous beam and its connexion with a column. Fig. 291 illustrates the cross-section of a beam and part of the connected slab. Fig. 292 represents the arrangement of bars and

stirrups in beams with single and double reinforcement, each stirrup having a kink at one side serving to clip it to the main bar, as shown by the enlarged detail in Fig. 293. Columns are reinforced by four or more round longitudinal bars with lateral ties in sets of four or more spaced at suitable intervals apart vertically. Walls are reinforced by vertical and horizontal rods along both faces of the concrete. Fig. 294 illustrates the main features of Hennebique beam, slab, and column construction. This drawing shows in perspective part of a Mouchel-Hennebique floor cut away to

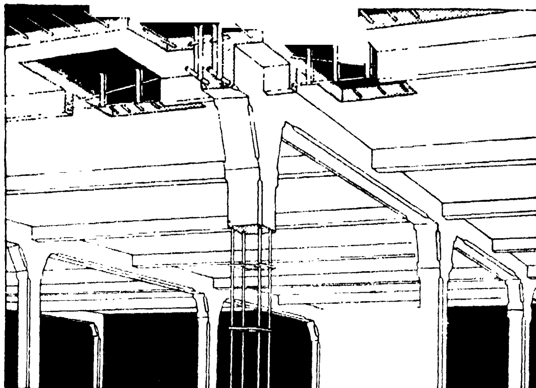


FIG. 294.—General application. (Mouchel-Hennebique System.)

illustrate the arrangement of the reinforcing bars and stirrups in the main and secondary beams and connecting slab. Part of one of the supporting columns is drawn without concrete, so as to show the longitudinal and transverse reinforcement.

Trussed Concrete Steel Co., Ltd. (*Kahn System*).—The specialty of this firm is a patented bar of square section having two projecting wings along

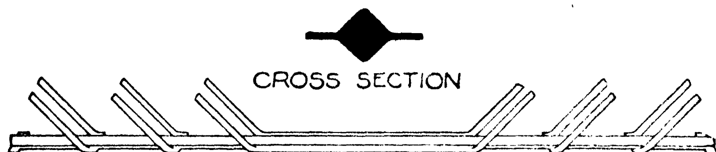


FIG. 295.—Kahn Trussed Bar.

opposite corners. For use in beams, slabs, and columns the wings are partly separated by shearing so that the loose portions can be bent up at an angle of 45 degrees to form web reinforcement for members acting as beams, and lateral reinforcement for columns and struts. Fig. 295 represents the bar as prepared for beams and floors, and Fig. 296 is a diagram showing in perspective the arrangement of reinforcement in beams,

columns, and slabs. In the case of columns, the bars are sometimes left unsheared and are braced by lateral ties at frequent intervals apart.

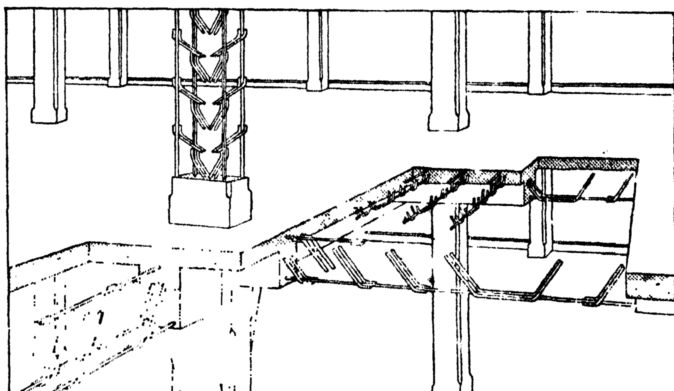


FIG. 296.—General application of Kahn System.

Fig. 297 illustrates the ribbed bar provided by the same firm to meet the requirements of designers wishing to establish mechanical bond between the concrete and the steel used as reinforcement. The bar differs from a deformed bar where the fibres are distorted from the straight line, as the metal which comes in direct tension is rolled perfectly straight.

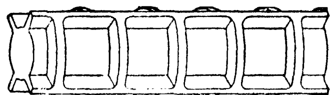


FIG. 297.—Kahn Ribbed Bar.

Wells System.—The distinctive feature of this system, which is worked by Stuart's Granolithic Co., Ltd., is the form of reinforcement employed. The bars used for withstanding tension are rolled in pairs joined by a very short web, making a section somewhat resembling a dumb-bell, or a double-headed railway rail. The twin bars are laid on their side or upright as most convenient, and in some cases extra single bars are introduced. The web reinforcement is provided by single stirrups of steel strip passed through an indenting mill giving a rough surface to which the concrete adheres, the stirrups being hooked around the main bars.

The general arrangement of the reinforcement is very similar to that adopted in the Hennebique system. It should be noted, however, that in beams where some of the bars are bent up towards the supports, the web of the twin bars is sheared, permitting the ends to be bent up, while in the middle portion the two bars remain connected. The method of reinforcing slabs is very similar to that adopted in the case of beams.

Columns are reinforced by ordinary longitudinal round bars, and the lateral reinforcement is formed by bands of round rods passing around the main bars and secured by hooking the ends together.

PRACTICAL CONSTRUCTION

The subjoined notes on the practical application of reinforced concrete to building construction are intended for the use of those engaged in the design and supervision of works, and may also be used as the basis of a general specification.

CONCRETE

Cement.—No cement should be used but that manufactured in compliance with and capable of passing the tests prescribed by the Revised British Standard Specification. The slow-setting quality therein described should always be adopted. Samples should be taken from different sacks in each delivery of cement and carefully tested to ascertain if in accordance with specification.

Storage.—Cement should be stored on the site of the works in a shed or other building affording protection against the weather and moisture from any source.

Sand.—All sand for reinforced concrete should be clean, sharp, and coarse, consisting of grains ranging from $\frac{1}{8}$ inch downwards in size. Fine sand with particles of uniform size is unsuitable.

Aggregate.—Pebbles or broken stone of hard and durable quality are the best aggregates. Limestone is liable to disintegration, especially under the influence of heat. Brick and coke make porous concrete of low compressive strength. Coke and other coal residues generally contain sulphur and acids which may affect the cement and the embedded steel. Blast furnace slags frequently contain sulphur and a large proportion of lime, and are liable to disintegrate in process of time.

Gravel.—Washed gravel or shingle used as aggregate should be in assorted sizes from $\frac{3}{4}$-inch down to $\frac{1}{8}$-inch gauge. Pebbles larger than $\frac{3}{4}$-inch gauge must be crushed before use. Sandy gravel, such as Thames ballast, must not be used in its natural state. The two constituents should be separated, washed, and again mixed in correct proportions.

Broken Stone.—Stone having a flaky cleavage should be rejected. Quarry dust and refuse should be removed by screening. The sizes of the particles should be from $\frac{3}{4}$-inch down to $\frac{1}{8}$-inch gauge.

Water.—Care should be taken to see that water used in the preparation of concrete is free from earthy or vegetable matter, acids, and alkaline salts.

Proportions of Concrete.—Although concrete mixed in the proportions of 1 : 2 : 4 by volume is largely used, it should be noted that concrete of this grade does not represent the best practice.

As the weight, and actual quantity, of Portland cement vary considerably per cubic foot, that material should always be proportioned by weight and not by volume. The following proportions are those recommended where the proportion of voids in the aggregate is not more than 50 per cent:

Machine-mixed Concrete.

6 cwt. Portland cement.
$13\frac{1}{2}$ cub. ft. sand.
27 „ „ aggregate.

Hand-mixed Concrete.

7 cwt. Portland cement.
13½ cub. ft. sand.
27 „ „ aggregate.

If the proportion of voids in the aggregate exceeds 50 per cent, the volume of sand should be increased in like proportion, and the weight of cement increased so that the richness of the mortar shall not be less than that provided for by the proportions stated above. The percentage of voids in the aggregate can readily be ascertained by filling a water-tight box of known capacity with aggregate, and measuring the quantity of water that can be added without overflowing. The percentage is then given by a simple calculation.

Consistency of Concrete.—Sufficient water should be added to the other ingredients to make a rather wet, or semi-fluid, mixture, capable of penetrating between all members of the reinforcement, and of filling the moulds completely. The concrete should be well tamped after deposition. Having once ascertained the proper quantity of water per batch, the proportion should be measured for each mixing so as to insure uniform consistency.

Mixing Concrete.—It is desirable that concrete should be mixed by machine, as mixing by hand never provides material of strength equal to that mixed by machine, unless the proportion of cement is increased. The supply of mixed concrete should not be appreciably in excess of requirements from time to time, the reason for this stipulation being that concrete must be used when freshly mixed in order to avoid loss of setting properties and strength. In warm weather special attention should be devoted to this point, as the setting of concrete is then accelerated.

STEEL

Quality and Testing.—Steel used as reinforcement should be of the quality described in the British Standard Specification for Structural Steel, and capable of passing the tests therein specified. Ordinary round rods, wire, and hoop steel are quite sufficient to meet all requirements in the way of reinforcement, but there is no reason why patented forms of bars should not be used, providing the metal is capable of passing the standard tests.

Storage and Treatment of Steel.—All deliveries should be sorted and stored under cover so that rods of any size can be readily withdrawn for use with the least possible amount of trouble. The steel should be free from oil, grease, dirt, paint, and loose rust or scale. A thin film of rust on the surface does no harm, and tends to increase adhesion between the metal and the concrete. After the latter has been applied, the oxide of iron combines with constituents of the cement to form a compound which prevents further corrosion. No rods should be welded, and all bending should be done cold by the gradual and uniform application of force.

A good practice is to flatten the ends of rods which have the diameter

of ½-inch and less, and to split and open out the ends of larger rods, as an additional precaution against slipping. A still more efficacious method is to bend the ends of the bars into the form of a hook.

CONCRETE WORK

Condition of Concrete.—All concrete should be used as soon as possible after mixing. No concrete should be used after it has commenced to set, and any batch giving evidence of initial set should be thrown away.

Sample Cubes for Testing.—Samples of concrete as supplied to the workmen should be moulded daily in the form of 4-inch cubes, marked and dated for subsequent identification. The cubes should be allowed to harden under conditions as nearly as possible the same as those applying to the parts of the work for which the bulk of the concrete has been used. The subsequent testing of the cubes will afford useful information bearing on the actual strength of the construction at the date or dates when the tests are conducted.

Concreting Columns.—Where moulds with one or more open sides are used, the first layer of concrete is deposited after the bottom part of the mould has been closed in to the height of from 6 inches to 9 inches. The concrete should be poked and rammed to expel air bubbles, and to cause the material to fill the space completely. Successive layers are deposited in a similar manner, the sides of the mould being built up with each layer of concrete.

Closed Moulds.—In cases where moulds with fixed sides are employed, care should be taken to see that the interior is perfectly free from rubbish and foreign substances before any concrete is deposited. A good plan is to pour in cement mortar, in the proportions of one part Portland cement to one part of sand, to the height of about 3 feet, poking the mortar to remove air bubbles before filling the mould with concrete. The use of mortar in this way will obviate the risk that the lower part of the column may consist chiefly of aggregate, and the upper part chiefly of cement and water. Closed column moulds of height greater than six diameters should be filled about halfway up from a side opening, and for the remaining part from the top.

Concreting Beams and Floors.—Main and secondary beams and floor slabs should be moulded in one continuous operation from the bottom to the top, and, if practicable, from side to side and end to end of the work. As work on a large scale cannot be completed without stoppage, the moulding of beams and slabs should be stopped between two supports, and, in resuming the deposition of concrete, the surface which has already set should be treated as described in the paragraph entitled "Jointing Concrete Surfaces."

The procedure to be followed in concreting beams and floors depends upon the nature and arrangement of the reinforcement. The following instructions are suitable for double reinforcement with some of the tension bars bent up towards the supports, and with web reinforcement in the form of U-shaped loops :

1. Spread a layer of concrete, from 1 inch to 2 inches thick, along the

bottom of the beam moulds, and after tamping secure the lower set of loops in position.

2. Lay the straight tension bars in the loops, see that they are in actual contact with the bottom of the loops, and fix them temporarily.

3. Spread another layer of concrete deep enough to cover the bars, and lay upon it the bent up tension bars between the projecting arms of the web loops.

4. Deposit more concrete until the bent up bars are covered, lay out the compression reinforcement, also between the arms of the web loops, and over the compression bars insert the upper set of web loops in an inverted position, and push them down into the wet concrete.

5. Spread a thin layer of concrete over the floor slab centring, and on it lay out the first series of tension bars in a direction at right angles with the axis of the beams. Deposit a second layer of concrete, and lay out the second series of tension bars at right angles to those of the first series and parallel to the beams. Cover these bars with concrete, lay out the compression bars at the proper level, and finish the floor slab to the required thickness, incorporating the projecting ends of the web loops in the final layer of concrete.

The foregoing procedure can readily be varied to suit the details of any design. Moulds and centring for concrete are described and illustrated in Chapter V.

Jointing Concrete Surfaces.—Before adding fresh concrete to work that has already set, the face of the old concrete should be roughened with a cold chisel and covered with cement grout. The new concrete should be well rammed on the face of the old work.

Concreting in Warm Weather.—As moisture is necessary during the process of setting, freshly laid concrete should be protected from the direct rays of the sun, and sprinkled from time to time as may be found requisite to keep it moist.

Concreting in Cold Weather.—Concrete laid in cold weather should be covered over to protect it against frost, and no concreting should be done during severe frost.

Surface Finish.—Concrete intended to be covered by other materials should be deposited so as to leave a rough surface.

Stucco Finish for Exposed Surface.—Instead of rendering the face of the concrete in the ordinary way, the surface of the work should be rubbed smooth, and either brushed over with cement grout, or skimmed with mortar mixed in the proportions of one part Portland cement to two parts of sand.

Rock Finish for Exposed Surface.—The stones of the aggregate should be laid bare after removal of the moulds by washing away the cement and sand with the aid of a stiff wire brush, or by dissolving out the cement by means of dilute hydrochloric acid. After the application of acid, the surface should be washed with an alkaline solution and then with clean water.

Protection of Green Concrete. — When concrete has commenced to set it should be protected from shock, vibration, and anything tending to interfere with the process of setting. No load should be imposed on

beams, floors, columns, or other parts of the structure unless permitted by some person in authority.

PLACING REINFORCEMENT

General Procedure.—The number, size, and position of all rods, wires, or strips forming part of the reinforcement must be in exact accordance with the working drawings. This is a point to which special attention should be paid by the contractor's foremen and the clerk of works. No member of the reinforcement for beams and columns should be at a distance of less than 1 inch from the inside of the mould.

Column Reinforcement.—In cases where the reinforcement consists of vertical bars and transverse links or ties threaded on the main bars, the latter should be fixed in position, and the links slid to the top of the mould and tied there before concreting is commenced. Then, as successive layers of concrete are deposited, the links can be brought down one set at a time and embedded in place. In cases where the reinforcement is in the form of longitudinal bars with attached wings acting as lateral reinforcement, or where longitudinal bars are applied in conjunction with a spiral winding of wire, or with a continuous sheet of wire network or expanded metal, the whole of the reinforcement should be fixed in position before the commencement of concreting. All longitudinal bars should be perfectly straight and fixed truly vertical. Steel wire or templates should be used to insure the correct spacing of the main bars at the top and bottom of every column, and care must be taken to see that none of the bars are too near the inside surface of the moulds. The longitudinal bars should have direct bearing on the steel of the column base, or upon the corresponding bars of the column length below. The upper end of every bar should project through the floor above, and may conveniently be finished with a pipe socket or sleeve to act as a guide for the bar in the next column length. All ties, links, and other forms of lateral reinforcement should be taut so as to brace the main bars effectively.

Beam Reinforcement.—In beams having only longitudinal tension bars and independent web loops, or tension bars with attached web members, the reinforcement can be placed and temporarily fixed in position before concreting is commenced, or after a thin layer of concrete has been spread along the bottom of the mould. In beams having tension and compression reinforcement with independent web loops about the tension bars, and inverted loops of similar character about the compression bars, the usual course is to deal with the tension and lower web units as described in the paragraph entitled "Concreting Beams and Floors." Then after a sufficient amount of concrete has been deposited, the compression bars are laid and fixed in place, the inverted web loops are pushed down into the concrete and the mould is filled to the top. In beams having tension and compression reinforcement with web members wrapped around and secured to both series of main bars, the whole of the reinforcement should be laid and fixed in place before concreting is started. The same procedure is necessary in the case of beams having tension and compression bars with attached

web members, or with reinforcement built up in the form of a connected skeleton frame.

Slab Reinforcement.—Floor slabs are analogous to beams, and the methods of dealing with their reinforcement are essentially similar to those described in the preceding paragraph.

PROVISION FOR PIPES, CONDUITS, AND PLANT

Drawings.—Plans should be prepared in advance, showing the position of all steam, water, and gas pipes, electric cables, and other conduits which have to be encased in the concrete or to pass through it, and showing also the position of bolts for fixing mechanical plant of any kind. It is preferable that pipes and conduits generally should be run on the face of the concrete, so that they may be open to inspection and repair.

Pipes and Pipe Fastenings.—Pipe hooks and hangers should be screwed into small blocks of wood moulded in columns, beams, slabs, or walls during construction. In places where pipes have to pass through floors or walls ferrules should be moulded in place during the work of concreting.

Electric Cables and Wires.—Provision for electric cables and wires can be made by embedding tubes near the surface of the concrete, if they cannot be conveniently run along the face of the work. If the conduit tubes are not strong enough to withstand the pressure of the wet concrete, they should be filled with sand and plugged at the ends, the sand being removed after the concrete has set.

Bolts and Hooks.—Holes for bolts and hooks can readily be moulded in the concrete, and in some cases it may be convenient to mould fastenings for mechanical plant directly into the concrete during construction.

Cutting Concrete.—No cutting of reinforced concrete should be permitted except by special permission. Contractors for pipes, electric wiring, and mechanical plant should be required to fix their apparatus at points where provision for fixing has been made in the concrete. In order that no question shall be raised as to the suitability of such points, the contractors should be given an opportunity of suggesting any alterations that may be desirable for the proper execution of their work.

LOAD TESTS

Test Load.—The maximum test load, after the work has been allowed ample time for hardening, should be not more than 50 per cent in excess of the normal load for which the construction has been designed.

Nature of Loading.—The loading should be uniformly distributed over the area selected for test, and may consist of pig-iron, ballast, brick, stone, or any other suitable material. Care should be taken to stack the loading so as to avoid arching action tending to relieve the middle portion of the test area from receiving its full share of the load.

Permissible Deflection.—When under the full test load no part of the construction should develop proportionate deflection of more than one six-hundredth of the span, or such deflection as may be specified in local building regulations, and shortly after removal of the loading the construction should return to its original form.

Measurement of Deflection.—Before the application of any loading, three sensitive deflectometers should be placed in position beneath each beam tested, one instrument at the middle of the span and two instruments close to the supports. The net maximum deflection is readily ascertained by deducting the mean deflection, or settlement, at the supports from the total deflection at the middle of the span.

REINFORCED BRICKWORK

Brickwork reinforced by iron or steel in different forms has been used to no inconsiderable extent in building construction. In some cases the reinforcement is passed through holes in the bricks, and in others it is laid in the mortar joints. In some classes of construction reinforced brickwork proper is employed alone, and in others in conjunction with plain or reinforced concrete. Reinforced brickwork can be designed by the aid of the rules for reinforced concrete, given in Part IV. Various methods of executing and applying reinforced brickwork are given in the subjoined notes on three systems which have been largely employed in this country and abroad.

Cottancin System.—The reinforcement in this system is applied in the form of thin rods passing through holes pierced in the bricks, as repre-

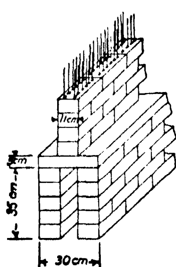


FIG. 298.

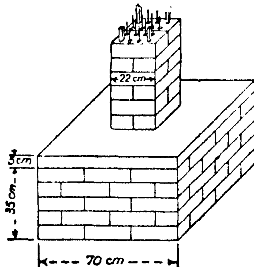


FIG. 299.

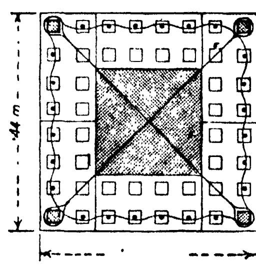


FIG. 300.

Reinforced Brickwork. (Cottancin System.)

sented in Figs. 298 to 300. The rods are secured around horizontal flat bars along the top and bottom bed joints, and also at levels where openings occur, or connexions have to be made, the horizontal bars being sometimes replaced by horizontal wires interwoven with the vertical wires. The bricks used measure $8\frac{5}{8}$ inches by $2\frac{3}{8}$ inches by $3\frac{1}{8}$ inches with one row of four perforations $1\frac{3}{16}$ inches square. Bricks of larger dimensions are also used with two rows of perforations. The narrow type of brick is used for constructing hollow walls and partitions, and the wide type for solid work. Fig. 298 represents part of a wall and footing, Fig. 299 illustrates a column and hollow base, and Fig. 300 is a section of a column with a centre core of concrete.

Cottancin walls have been constructed as thin beams of great depth, to span wide openings. An example of the kind is illustrated in Fig. 301, which represents a wall at the Electric Tramway Depot, in the Rue de Lagny, Paris. This wall is only 11 centimetres thick, with the depth of

5·5 metres and the span of 16 metres. The reinforcement consists of flat steel bars, 40 millimetres by 16 millimetres, arranged to form a triangulated system of bracing as shown. The bars are embedded in the brickwork, and securely connected with the horizontal and vertical reinforcement of the side walls and roof, and with a horizontal plate, 40 millimetres by 18 millimetres, at the bottom of the wall. As demonstrated by tests conducted by the French War Department and committees of the Ponts et Chaussées, construction on the Cottancin system possesses great strength.

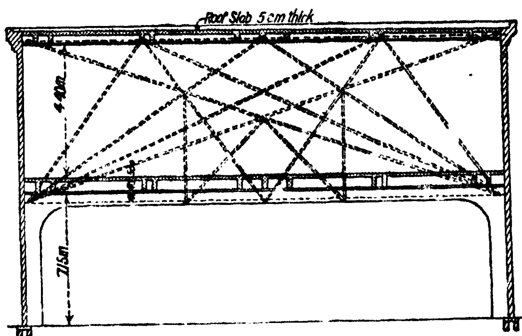


FIG. 301.—Reinforced Brickwork. (Cottancin System.)

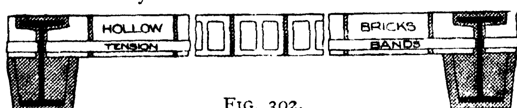


FIG. 302.

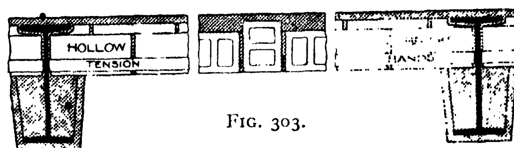
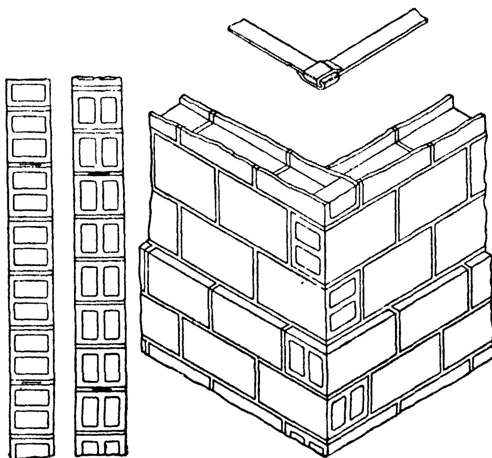


FIG. 303.

Kleine System.—This system embodies the use of hollow bricks with closed ends set in cement mortar wherein are embedded iron or steel tension bars, usually in the form of flat strips. This type of construction is applied chiefly to the construction of floors, walls, roofs, and stairways. Figs. 302 and 303 are sections showing the arrangement of the bricks and tension bands in typical floors constructed without joists be-


FIG. 304. FIG. 305.
Reinforced Brickwork. (Kleine System.)

tween the supporting girders. Fig. 304 represents a wall 4½ inches thick, and one 6 inches thick. Fig. 305 shows the manner in which angles are bonded, the small detail at the top representing the hooking of the tension bands at the corner. Slopes for stairways, inclined roofing, and flat roofing are constructed similarly to floors.

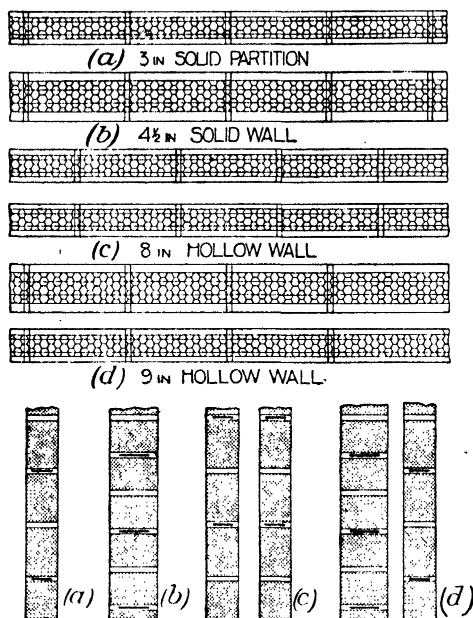


FIG. 306.—Reinforced Brickwork Walls. (Brown System.)

Brown System.—The special type of reinforcement employed in this system is made by Messrs. Richard Johnson, Clapham, and Morris, Ltd. It is in the form of netting with tension strands throughout, and laid in the joint of every alternate course of brickwork. The system is chiefly applied to the construction of exterior walls, interior walls, partitions, wall lintels, and piers. Fig. 306 includes drawings showing the construction of 3-inch solid partitions, 4½-inch solid walls, 8-inch hollow walls, and 9-inch hollow walls. Fig. 307 is a section

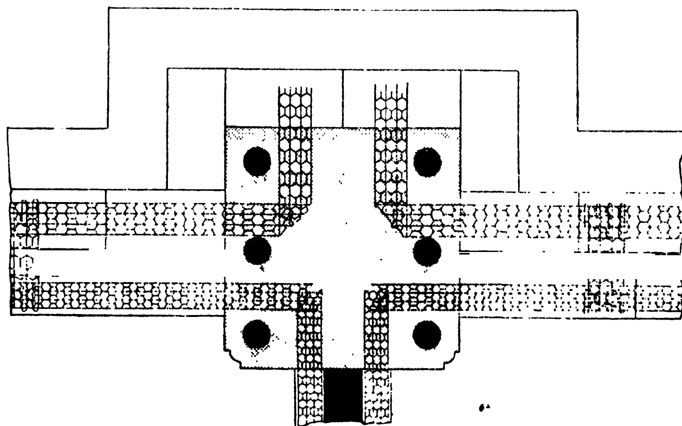


FIG. 307.—Reinforced Brickwork Walls (Brown System.)

illustrating the bonding of reinforced brick walls with a reinforced concrete column, and Fig. 308 shows a similar method of dealing with reinforced brick walls enclosing a built-up steel stanchion. As an indication of the load-bearing capacity and lateral resistance of reinforced brick walls, the patentees state that for the span of 15 feet between

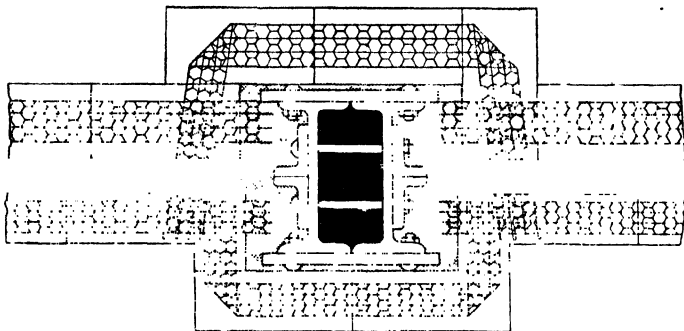


FIG. 308.—Reinforced Brickwork Walls. (Brown System.)

supports a 4½-inch solid wall will carry a superimposed load equal to 5 cwt. for every course reinforced, and will have the lateral resistance of 2½ cwt. per square foot, the corresponding values for a 9-inch hollow wall of 3-inch and 4½-inch brickwork being 7 cwt. for every course reinforced, and the lateral resistance of 3 cwt. per square foot.

CONCRETE BLOCKS

Plain Concrete Blocks.—Concrete blocks of all classes required to complete a building, except lintels or other parts exceeding 48 inches long, can be moulded in machines supplied for the purpose by various firms. Fig. 309 represents part of a cavity wall built with two series of solid 4½-inch blocks bonded by wrought-iron ties such as are employed for brickwork.

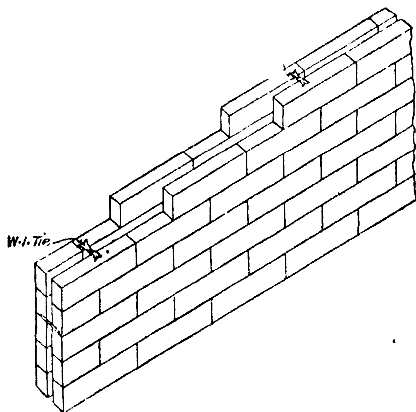
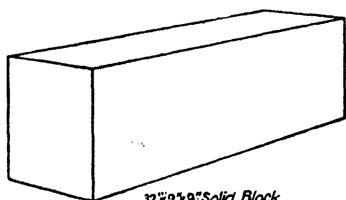
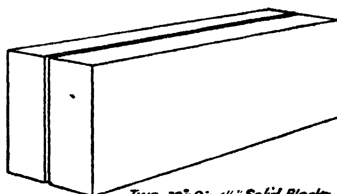
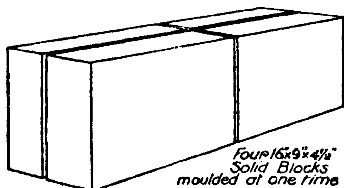


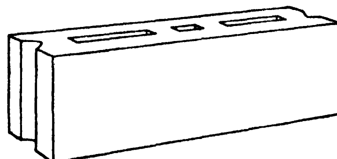
FIG. 309.—Concrete Block Hollow Wall.

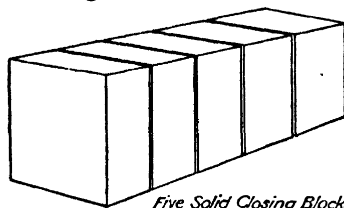
Fig. 310 includes a number of diagrams illustrating some of the numerous forms of blocks that can be moulded in the machines, and it should be noted that one or more of the faces of each type of block can be finished with any of the following surfaces: Imitation rock, plain dressed, herring-bone, scutched,

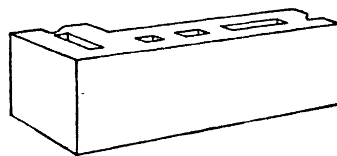


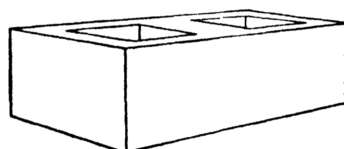


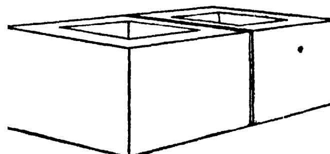


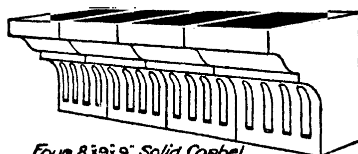


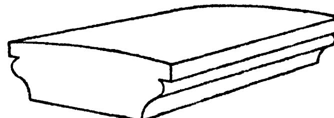


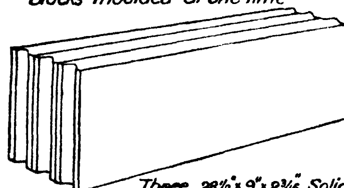












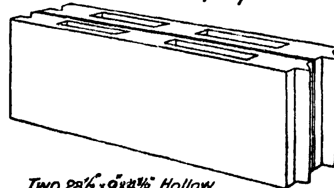


FIG. 310.—Typical Forms of Concrete Blocks.

boasted, tooled, sparrow-pecked, chamfered, panelled, and ornamental moulding.

Solid and hollow blocks are laid in the same way as bricks or cut stone, care being always taken to wet the blocks so that they shall not abstract water from the mortar.

The concrete for making blocks should be of quality similar to that recommended for reinforced concrete work, and care must be taken to see that the blocks are thoroughly seasoned before use, as freshly-made blocks shrink considerably. The appearance of the surface finish can be varied by the choice of aggregates, and if desired the face of the finished work can be treated by one of the methods already described in the paragraphs dealing with the surface treatment of reinforced concrete.

Reinforced Concrete Blockwork (Mouchel System).—As an alternative to moulded wall panels between the exterior columns and wall lintels of reinforced concrete skeleton buildings, and for the construction of interior partitions and walls, Messrs. L. G. Mouchel and Partners have introduced a method of construction involving the employment of concrete blocks or slabs, reinforced by vertical and horizontal steel bars, the whole being rendered monolithic by horizontal bed joints and vertical grouting.

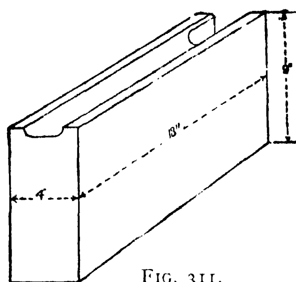
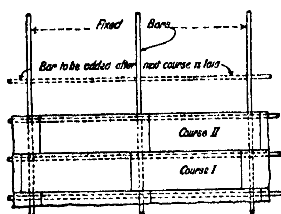


FIG. 311.



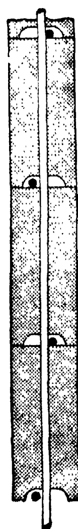


FIG. 313. FIG. 312.

Reinforced Concrete Blockwork.
(Mouchel System.)

Fig. 311 shows in perspective one of the blocks, which can be made of any required dimensions. Where intended to be adopted in place of bricks, the blocks are usually 4½ inches thick by 9 inches deep by 18 inches long, and if required for thin curtain walls or partitions, the blocks are moulded in the form of slabs 2 inches or more thick by about 3 feet square, or of any convenient size. Each block is moulded with two grooves, one horizontal and the other vertical. The horizontal grooves are wide enough to permit the horizontal bars to be laid as shown in Fig. 312, the vertical grooves being of dimensions sufficient for the vertical bars, and also to provide for breaking the joints, as indicated in Fig. 313. The horizontal bars are laid after each course has been completed, their ends being embedded in the columns at either side. Fig. 313 represents part of a wall constructed in accordance with the method described.

CHAPTER XV

FIRE-RESISTING CONSTRUCTION

By W. Noble Twelvetrees, M.I.Mech.E, M.Soc.Ing.Civ.

Definition.—The term "fire-resisting" is now generally employed by British architects instead of the term "fireproof" in connexion with building construction. American architects and public authorities, and many of the specialist firms in this country devoting attention to fire-resisting materials and methods of construction, still make use of the term "fireproof," disregarding the well-known fact that not one of the materials available for building construction is capable of continued resistance to fire. While a building constructed entirely of incombustible material, with adequate fire protection for structural metal, may properly be classified as "fire-resisting," the employment of timber and other combustible materials for interior fittings, window and door frames, and the neglect of safeguards against the spread of fire from one part to another, or the entrance of fire from the exterior, cannot fail to detract very seriously from the safety of a building which complies in other respects with accepted principles of fire-resisting construction.

Fire-Resisting Materials

Brick.—Experience shows that well-burned brick is unsurpassed by any other material in respect of resistance to fire, but it should be noted that in a severe fire the heated side of a brick wall is apt to expand considerably, sometimes to the extent of bringing down the wall, while the bricks suffer injury by cracking and flaking.

Terra-Cotta.—As used for structural purposes, terra-cotta is produced in three varieties, distinguished as *dense, semi-porous,* and *porous.* Another variety known as *ornamental terra-cotta* is made for decorative purposes.

Dense Terra-Cotta is made from different kinds of clay, the composition of the mixture varying with the place of manufacture. Although strong and hard burned, it is apt to crack and disintegrate under severe heat, and blocks with two or more interior air-spaces are liable to have the outer webs destroyed by heating and subsequent cooling by water.

Semi-porous Terra-Cotta is made by burning fireclay, with which about 20 per cent of ground coal has been mixed. The coal assists the process of burning and renders the product more or less porous. This variety is superior to dense terra-cotta as a fire resistant, and may be heated to high temperatures without cracking.

Porous Terra-Cotta is made by mixing sawdust with the clay, the

burning of the sawdust leaving a light and porous product. This variety is a good non-conductor of heat, its efficiency in manufactured forms being improved by a cellular structure. If carefully made, porous terra-cotta will not crack as the result of unequal heating, or of cooling by water after having been heated to high temperatures.

Ornamental Terra-Cotta varies in colour with the tint of the raw material, which consists of pure clay of selected quality and free from stones and grit. Severe fire and water tests show that ornamental terra-cotta is not materially injured by high temperatures and sudden cooling, although decorative details may suffer.

Stone.—Few building stones are capable of withstanding severe heat. Consequently stone should be used sparingly in fire-resisting construction, and some varieties should not be employed at all. Granite disintegrates violently when exposed to flames, limestone and marble are readily calcined by intense heat, while sandstone, if fine-grained and compact, usually withstands heat fairly well, but its destruction is simply a matter of time.

Concrete.—The resistance of concrete to continued heat depends very much upon the composition of the material. Aggregates liable to disintegrate or calcine readily naturally prejudice the resistance of the concrete. Coal residues, if very carefully selected and cleansed, make concrete of high resistance, although such products are apt to burn away under high temperatures, and should never be used in conjunction with metal reinforcement owing to the risk of corrosion. Well-made concrete may be ranked with hard brick as one of the most effective fire-resisting materials available.

Mortar.—Lime mortar was formerly regarded as a more effective fire resistant than cement mortar, but improvements in cement manufacture have rendered the latter superior. Applied on metal lathing for the construction of partitions, cement mortar offers sufficient resistance to restrict the passage of fire for a time, the endurance of the barrier so formed being affected mainly by the thickness of the material.

Plaster of Paris.—This material is less effective than Portland cement, as it cracks and breaks away at comparatively low temperatures, and is readily eroded by water thrown upon it for the purpose of fire extinction.

Patent Cements and Plasters.—Many special preparations of this class offer considerable resistance to fire and water, and are capable of being employed with advantage for the protection of metal and in structural elements intended to retard the spread of fire.

Timber.—Notwithstanding the combustibility of wood, this material has some claim to be considered as one capable of effective resistance to fire within moderate limits. If employed in large scantlings timber burns very slowly, providing the flames cannot get round its sides or ends. After it is charred to a certain depth, the charcoal formed, being a non-conductor, protects the surface and retards combustion.

Non-flammable Wood is prepared by impregnating the fibres with chemicals. Timber that has been thoroughly treated is of much value in building construction where importance is attached to the elimination of substances helping to feed the flames in the early stages of a fire.

Wired Glass.—Ordinary glass in which wire-netting has been embedded possesses the valuable property of remaining intact, even if the glass has been cracked by shock or by intense heat. Many severe fires have shown that wired glazing is capable of preventing the passage of flames unless the heat is so great as to melt the glass.

Asbestos, Silicate Cotton, and Slag Wool.—These materials are largely used in fire-resisting partitions, roofing, and other details. While practically indestructible in themselves, their efficiency depends largely upon the composition and manufactured form of the slabs or products in which they are incorporated.

Iron, Steel, and Other Metals.—Metals can only be regarded as fire-resisting materials of limited efficiency. Their incombustibility and capacity for withstanding sudden and brief attacks render some of them very serviceable in the early stages of a fire, and particularly for protecting the exterior of a building from sparks, burning fragments, and flame from other buildings. Iron and steel employed as structural members must be adequately protected by fire-resisting material to obviate failure as the result of excessive heat.

Wrought-iron and steel commence to fail at temperatures of from 1000° to 1200° Fahr., and cast-iron yields at temperatures ranging from 1300° to 1500° Fahr. From these figures and the subjoined table of melting points, the reader may form a trustworthy idea of the limits of fire-resistance applying to metals commonly employed in building construction.

MELTING POINTS OF METALS (MOLESWORTH)

Metal.	Temperature.
Wrought-iron and steel	3000° Fahr.
Cast-iron	2200 ,,
Copper	1950 ,,
Brass	1834 ,,
Zinc	736 ,,
Lead	612 ,,

FIRE-RESISTING DESIGN

Importance of Scientific Design.—The best fire-resisting materials, the best types of fire-resisting construction, and the best fire-preventing and fire-fighting equipment may be rendered useless in the absence of proper planning. Chief among the risks to be guarded against by the designer of a fire-resisting building are: (1) The ignition of structural materials, and materials used in the form of permanent fittings near the point of origin of a fire. (2) The communication of fire from the place of origin to other rooms on the same story, or from the story of origin to other stories. (3) The entrance into a building of fire from the outside.

Danger of Combustible Materials.—It is not sufficient to employ fire-resisting materials in the main structural features, for many disastrous fires prove that buildings supposed to be constructed on the best fire-resisting principles are not really safe if combustible materials are present to any considerable extent. The complete destruction of six stories of the Mutual Life Insurance Building at San Francisco is one example that

may be cited as an illustration of the fact that a relatively small proportion of wood in a structure consisting almost entirely of incombustible materials may furnish enough heat to cause general destruction. Hence a most important point is the greatest possible limitation of the amount of combustible material in minor structural details, partitions, and fittings generally.

Advantage of Fire Barriers.—Assuming the walls and ceiling of any area in a building are capable of withstanding and restricting a local outbreak of fire, there is still the risk of dangerous extension if the area in question is of large extent, of communication to areas on the same

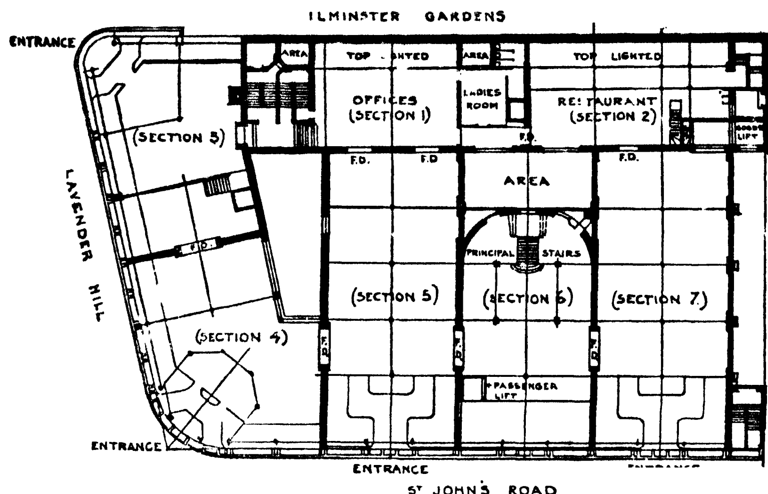


FIG. 314.—Plan of Building divided by Fire-Barriers.

story through doorways or glazed partitions, and of extension to stories above that of the originating source by way of staircase wells, lift shafts, light wells, or vertical ducts. The planning of fire barriers necessarily depends upon the requirements of the owner or tenant, as the case may be. In business premises, the convenience of large undivided spaces for the manufacture, storage, or sale of goods is usually appreciated more than the safety ensured by efficient barriers for the isolation of fire. The difficulty of subduing fire in a large open area was clearly illustrated by the disaster at Clapham Junction, London, in December 1909, when the accidental ignition of inflammable goods in a shop window caused a fire which rapidly spread through an extensive range of undivided shops and involved the complete destruction of the whole building. In the subsequent reconstruction the lesson of the disaster with relation to the point now in question was evidenced by the establishment, between the various departments, of efficient fire walls with fire-resisting doors to all openings provided for the free circulation of the public. Fig. 314 is a

ground floor plan of the new building showing the fire walls and fire doors isolating the seven sections into which the area is divided.

In buildings where each story is divided up into rooms of moderate size by fire-resisting walls or partitions, it is easy to restrict the spread of fire by doors of approved fire-resisting construction, and even doors of slow-burning type are not to be undervalued. Nevertheless, safeguards such as these are insufficient so long as open stairways, lift shafts, light wells, and other open communications are permitted between the various floors.

Conventional design usually makes the staircase a prominent architectural feature. In some commercial buildings it is thought necessary to place the staircases where they cannot fail to attract attention, this requirement leading to designs that may be effective architecturally and exceedingly ineffective from the standpoint of fire-prevention. Since

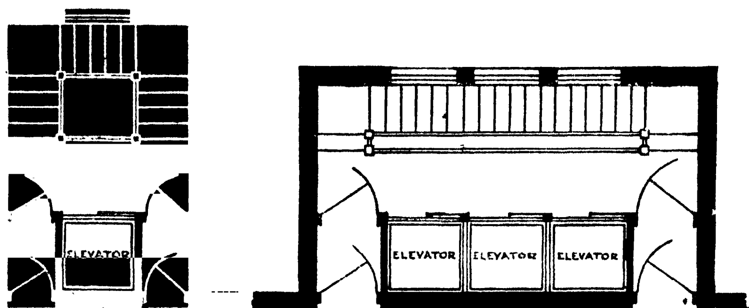


FIG. 315.—Two Arrangements for isolating Stairs and Lifts.

the general adoption of lifts, the staircase well has been largely utilised as a convenient place for the installation of one or more lifts. To make it impossible for staircase and lift wells to act as flues for the conduction of flame and smoke throughout an entire building, these vertical shafts should be completely isolated by fire-resisting walls and doors, and additional safety would be afforded by an independent fire door opening directly to the outside of the building at ground level. The stairs themselves must obviously be capable of effective resistance to fire. Fig. 315 illustrates two arrangements proposed by Mr. J. M. Carrère, the well-known American architect, for the isolation of stairways and lifts.

Interior light wells open to the different floors of a building constitute a serious fire risk, even if provided with rolling shutters for retarding the passage of flame. Light wells, in the form of interior courts, are far less dangerous, although capable of acting as flues if flames break into them from any of the surrounding rooms or floor areas.

Window Protection.—The most effective means of preventing the entrance of fire into a building from adjacent structures is to protect all window openings by rolling steel shutters kept cool by automatic sprinklers, and to use fire-resisting or slow-burning exterior doors. In buildings occupied by a number of tenants it is probably quite impractic-

able to arrange for the closing of fire shutters at a given time every evening, as can easily be done in the case of buildings occupied by the owner or one tenant. Nevertheless, the risk of exterior fire can be greatly reduced by the employment of metal window frames and sashes fitted with wired glass, either in large panes or in the form of small sections inserted in metal framework of more or less ornamental design.

The value of wired glass was abundantly demonstrated in the San Francisco fire, and this material can be employed with much advantage in skylights, area windows, and all exterior windows. Polished plate glass with fine wire reinforcement is by no means unsightly, and there is no reason why the wire meshwork should not be made an attractive feature.

Channels for Pipes and Wires.—Injudiciously placed gas-pipes and electric wires involve serious risks. The escape of gas from a broken pipe adds fuel to a fire already started, and electrical short-circuits have set many buildings on fire. The designer of a fire-resisting building should make careful provision for the installation of all pipes and wires, instead of leaving the arrangement to the building contractor or to sub-contractors, as too often is the case. Vertical pipe shafts connecting the various floors of a building are efficient flues for the encouragement and distribution of fire, and the utilisation of fire casing around columns and stanchions as pipe ducts is bad for the same reason, and also because the efficiency of the protective casing is liable to be disturbed by workmen when access to the pipes becomes necessary. Vertical channels for pipes and other conduits should be lined with fire-resisting material and partitioned off at the level of each floor with metal lathing and plaster, or any suitable composition which can at any time be cut away and renewed. In order to enable the pipes to be fully exposed for examination or repair, the front of the shafts can be provided with fire-resisting covers screwed in place. Similar channels can be formed in the floors, lined with fire-resisting material, stopped at the ends, and furnished with removable covers.

Practical Construction

Columns and Column Protection.—In modern building construction, whether with self-supporting walls or of the steel-frame type, metal columns are very generally used for carrying loads of a kind which were formerly imposed on masonry walls or piers. In this country, column loads range up to some 1500 tons per column, and in the United States considerably greater loads are supported by the columns of lofty buildings. As interior columns may be attacked from all sides, it is particularly necessary that they should either be formed of fire-resisting material or be adequately protected against the action of fire.

Fire-Resisting Columns.—Reinforced concrete and reinforced brick are practically the only fire-resisting materials available for constructing such columns of reasonably small cross-sectional area in proportion to the load to be carried. A reinforced concrete column is quite capable of withstanding any heat likely to be attained in a fire without suffering material injury, and consequently does not need protective casing. The

result is that columns of this type can be constructed so as to occupy no more space than steel columns with an adequate thickness of protective material.

The investigations of Professor Woolston show that after exposing concrete to the temperature of 1500° Fahr. for one hour the temperature at the depth of 2 inches from the heated face barely reached 300° Fahr., a fact which is conclusive as to the immunity of the embedded steel from injurious effects. It should be noted that even if the heat were so intense as to destroy the structural value of the outer layer of concrete, the core of the column with its longitudinal and transverse reinforcement would still be capable of carrying the loads coming upon it, thereby obviating the collapse which necessarily follows the buckling of a metal column when softened by heat. This point is illustrated by Fig. 316, where the inner core of each column is shaded and the outer protection is left white. Reinforced brick offers an alternative which has not been applied to any appreciable extent in this country, although interesting examples are to be found in France. Fig. 317 illustrates the construction of the reinforced brick columns of a residential building in Paris, and Fig. 318 is a cross-section of reinforced brick columns with a central core of concrete in the church of St. Jean de Montmartre, Paris. In the latter the column is built up with six bricks to each course, the vertical reinforcement consisting of steel wires with the diameter of 4.4 millimetres except at the four corners, where square bars are used of sectional area equal to forty-three of the wires. In each horizontal joint steel wires of 4.4 millimetres diameter are woven in and out of the vertical reinforcement, and at intervals of 70 centimetres apart diagonal cross-ties are placed in the corresponding joints. This method of construction is more fully illustrated by Figs. 298 to 300, p. 212.

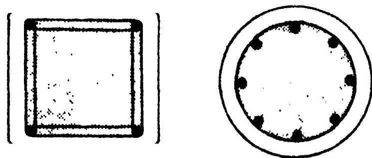


FIG. 316.

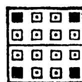


FIG. 317.

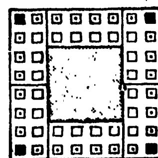


FIG. 318.

Column Protection.—Protective casings for columns should be capable of withstanding high temperatures for some hours, and of resisting attack by water from fire hose. They must be of low heat-conductivity, constructed so that they cannot be displaced by the destruction of combustible or other floors, they must be free from joints likely to open under the influence of heat, and designed so that any interior air-spaces are closed permanently at each floor.

Column casings may be formed of brick, concrete poured into moulds, concrete or cement mortar applied on metal network, plaster applied on metal network, and moulded blocks of terra-cotta or other fire-resisting material. Brickwork in cement mortar forms an

efficient protection, although not economical in respect of floor space. (For the thicknesses of protective casing required by the London County Council, see p. 193.)

Concrete can be poured into moulds of round, square, or other appropriate cross-section, so as to surround the column, thus forming an efficient protection and at the same time adding materially to the load resistance of the member. In the case of hollow columns the interior may be filled up with concrete as a safeguard against corrosion and as a means of securing additional strength and rigidity.

Fig. 319 illustrates the employment of concrete in this manner. The moulds for the casing should be made in short lengths, and the concrete

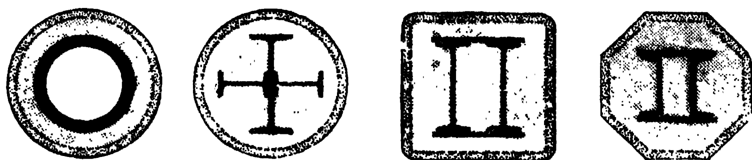


FIG. 319.

should be well rammed. The outer surface can be covered with plaster on metal lathing as an additional protection or for the purpose of decoration.

Fig. 320 shows an arrangement for encasing a hollow circular column in concrete by the aid of expanded metal serving the purpose of a mould, with lathing for the application of an exterior layer of plaster or cement. Quadrant clips made of flat steel bars and having lugs with punched or drilled bolt holes are fixed around the column at intervals, and vertical flat bars are bolted between the lugs. To these bars expanded metal is wired or fastened by clips, leaving an annular space of at least 2 inches between the lathing and the column. In order to avoid the inequality of composition caused by pouring concrete into long moulds, the metal should be fixed in short lengths, so that each batch of the concrete may be tamped before the next section is fixed in place. Fig. 321 shows a similar arrangement as applied to a built-up steel column of rectangular form. In either case the exterior of the lathing is covered with an outer layer of plaster or cement mortar, and it is a good plan to fill the interior of the column with concrete as a safeguard against corrosion and to ensure additional strength. The exterior plastering may be partly or completely destroyed by the action of fire and water, but this should be the extent of the damage.

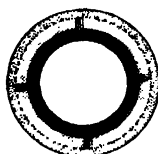


FIG. 320.



FIG. 321.

The methods illustrated by Figs. 320 and 321 can be modified as shown in Figs. 322 and 323 for the purpose of forming a protection of fine concrete, cement mortar, or fire-resisting plaster, separated from the encased column by an annular air-space. Although effective so long as it remains

intact, this type of casing is not advisable, as some portions of the material applied to the lathing are sure to fall off under the action of fire and water, leaving parts of the column exposed.

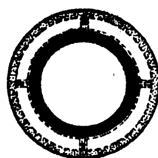


FIG. 322.

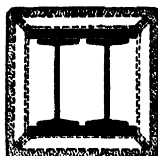


FIG. 323.

A more reliable method of forming a casing of plaster is to wrap the column with metal lathing, and after having plastered this with cement mortar or other approved material, to form an outer envelope of mortar or plaster applied to a second sheathing of metal, leaving an air-space between the two layers, the outer sheathing being held in place by vertical furring strips. Fig. 324 shows a typical example of this method, with two concentric air-spaces.

Blocks of concrete, terra-cotta, and various compositions such as are used for fire-resisting partitions are made for the purpose of casing iron and steel columns. Fig. 325 represents two forms of moulded concrete

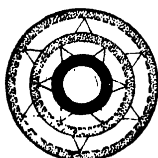
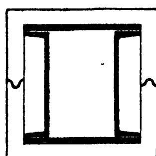


FIG. 324.



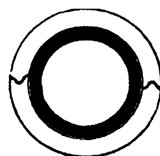


FIG. 325.

blocks for circular and rectangular columns respectively. Figs. 326 to 331 show different forms of casing blocks for circular and other columns and providing air-spaces, either between the blocks and the column or in the body of the blocks. The efficiency of casing formed of blocks is greatly increased by an outer sheath of metal lathing before application of the exterior coat of plaster or cement mortar. The lathing should be securely fixed so as to prevent any blocks or parts of blocks from falling away in consequence of injury by fire or water. In order to ensure protection of the metal under the most severe conditions, all types of casing formed of blocks, such as those illustrated in Figs. 326 to 331, should be protected by a second layer of blocks or of concrete on metal lathing. If the outer

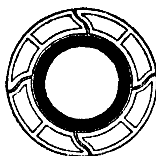


FIG. 326.

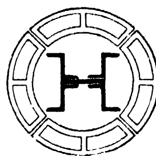


FIG. 327.

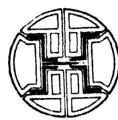


FIG. 328.

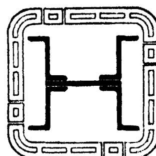


FIG. 329.

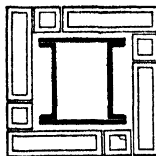


FIG. 330.

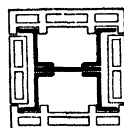


FIG. 331.

protection is of substantial and durable construction, it should not fail to keep the inner casing perfectly free from injury, and thereby to avoid any risk to the metal. Fig. 332 shows the double casing used in the Fair Building, Chicago, but it will be observed that the inner layer does not adequately protect the edges of the flanges, which would be exposed to flame if any part of the outer layer were displaced by fire.

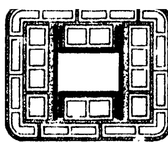


FIG. 332.

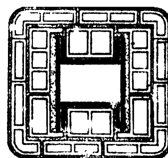


FIG. 333.

Fig. 333 represents a modification of the arrangement, with terra-cotta lugs extending in front of the flanges, and so providing a double envelope all round the column. In all cases where terra-cotta or other blocks are used it is desirable that a solid backing should be provided behind the casing in order to ensure stability and to guard against the entrance of fire or water through opened joints. The backing may be of concrete, or built up of terra-cotta or other approved material set in cement mortar.

Pipe Ducts and Column Casings.—As pointed out under the head of "Fire-Resisting Design," the practice of placing pipes inside column casing is one that should not be adopted. If pipes are arranged as shown in Figs. 334 and 335, repairs will necessitate removal of part of the casing, involving the risk that it will not be properly reinstated, and any leakage

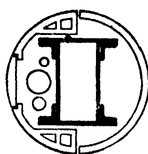


FIG. 334.

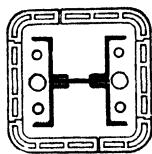


FIG. 335.

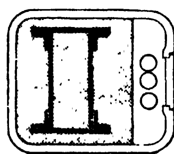


FIG. 336.

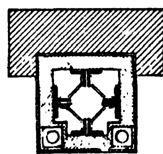


FIG. 337.

may lead to corrosion of the column. If pipes must be carried alongside columns, the methods illustrated in Figs. 336 and 337 will be found unobjectionable.

Girder and Beam Protection.—The only structural members in the nature of girders and beams which are capable of effective fire-resistance without casing are those made of reinforced concrete. Girders and beams of all other materials must be suitably protected. Most of the fire-resisting floor systems on the market include provision of more or less effective nature for the protection of floor beams. Therefore in the present section we consider only the question of casing girders and important beams exposed to a greater extent than floor joists to the action of fire and water, and the failure of which would involve disastrous results. The materials chiefly used for the protection of girders and beams are concrete or reinforced concrete, plaster on metal lathing, and terra-cotta blocks of special form. There is nothing more simple or more effective than concrete for the protection of girders and beams against

excessive heat, and the risk of surface injury to the concrete by water can be obviated by an outer sheathing of fire-resisting plaster.

Some authorities consider that the concrete protection should be at least 2 inches thick in order to provide a really efficient safeguard. The fact is that the adoption of such a thickness may defeat its own end, because the concrete is apt to crack and fall off, leaving the member without any protection in places. To obviate this tendency the concrete should not be much more than 1 inch thick at the flanges of the girder or beam to be encased, and should be reinforced by a meshwork of steel lathing secured to the flanges, all angles being rounded or splayed so as to offer the least possible resistance to the passage of flames and water. (For the thicknesses of protective casing required by the London County Council, see p. 193.)

Fig. 338 represents two similar forms of girder protection consisting of concrete reinforced by expanded metal and an outer layer of fire-

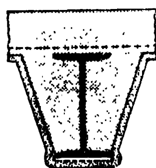
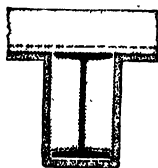



FIG. 338.

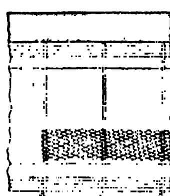
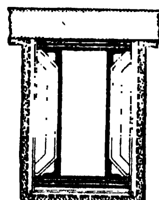



FIG. 339.

resisting plaster. Fig. 339 illustrates typical girder protection at the Great Western Railway Goods Offices, Paddington. The casing is formed by plaster on a substantial lathing of expanded metal. Although capable of offering considerable resistance to fire, this protection would be greatly improved by an arrangement permitting the girder to be solidly embedded in fine concrete, using the expanded metal as a mould and afterwards applying the outer layer of fire-resisting plaster. Fig. 340 shows the method adopted at Smithfield Market for protecting the exposed flange of girders projecting below arched floors, the materials employed being expanded metal and fine concrete. Fig. 341 illustrates a method of girder protection where the bottom flange is covered by a concrete slab moulded in advance and reinforced longitudinally by steel rods around which bands of steel strip are passed at intervals, the ends of the bands projecting so that the slabs can be secured to the bottom flange of the girder, leaving an air-space, ⅜ inch deep, between the concrete and the metal. The casing is completed by moulding concrete around the girder and applying an outer sheath of fire-resisting plaster. Fig. 342

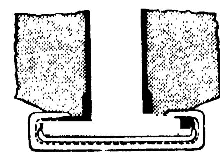


FIG. 340.

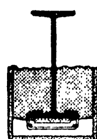


FIG. 341.

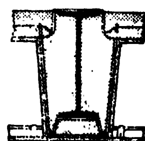


FIG. 342.

gives details of another type of concrete casing, which is filled in between the girder and a meshwork of steel-wire lathing stiffened at intervals by U-shaped stirrups and also by longitudinal rods. The lathing is held at the distance of 2 inches away from the girder, and after concreting has been completed, the exterior is plastered ⅝ inch thick.

Numerous forms of concrete and terra-cotta blocks are made for the protection of girders and beams. The chief risks incidental to the employment of all such blocks are that portions may crack and fall off

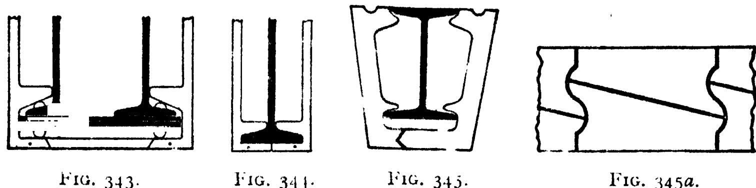


FIG. 343. FIG. 344. FIG. 345. FIG. 345*a*.

under the influence of heat, and that unless the blocks are mechanically fixed, the cement joints may be destroyed and allow the casing to fall away at the under side. Concrete casing blocks should be reinforced by wire-netting or expanded metal to prevent fragments from falling; terra-cotta blocks should be of the porous quality, and blocks of all kinds

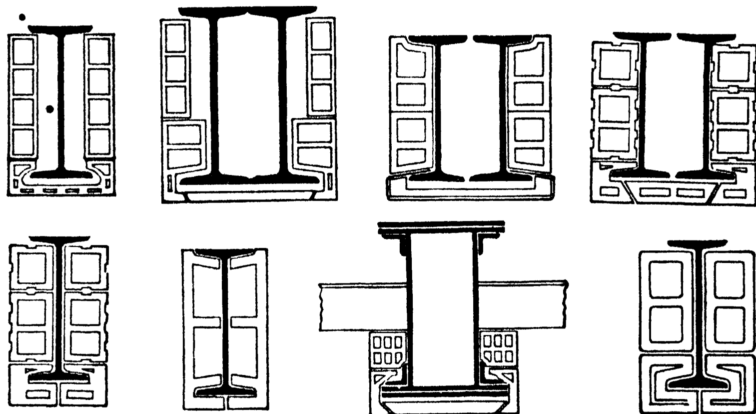


FIG. 346.—Terra-Cotta Girder Casings.

should be mechanically fixed. Terra-cotta blocks ought not to be less than 4 inches thick, with large interior air-spaces. In cases where the most reliable fire protection is desired, the casing of blocks should be sheathed with metal lathing and fire-resisting plaster. Figs. 343 and 344 show two forms of concrete block casings for girders. Fig. 345 shows another type of concrete casing with interlocking joints, the soffite being shown by Fig. 345*a*, and Fig. 346 illustrates several kinds of terra-cotta casings for girders and beams of different types.

Fire-Resisting Floors.—The design and construction of fire-resisting

floors are perfectly simple matters, the only complication presented by the general subject being occasioned by the large number of patented floor systems which have been introduced within comparatively recent times, and continue to be brought forward by commercial firms. It would be impossible in the present chapter to describe and illustrate all the patented floors that are made, and to select some for description would be unfair to those omitted. Therefore the subjoined notes deal merely with the characteristics and efficiency, from the standpoint of fire-resistance, of the general types which cover individual varieties of floor construction.

As a matter of convenience, floor systems may be divided into the following groups :

1. Brick Floors.
2. Concrete Floors.
3. Terra-Cotta Floors.

Brick Floors.—Arches of brick supported by piers of the same material have long been used, and although very efficient they are too

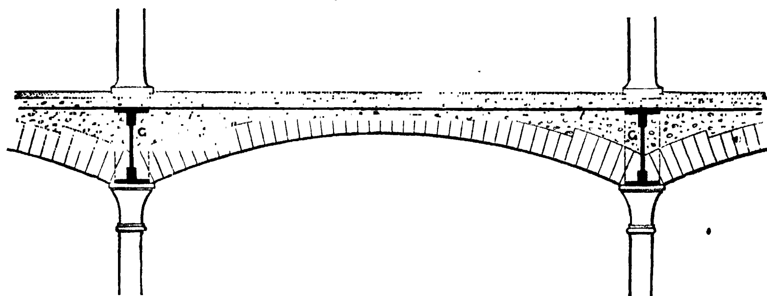


FIG. 347.—Early Form of Solid Brick Floor Arch.

cumbersome for employment except in the bottom story of ordinary buildings. A lighter form of construction introduced about the beginning of the nineteenth century consisted of brick arches supported by cast-iron beams, which were successively replaced by wrought-iron and mild steel beams in subsequent modifications. Fig. 347 represents an early type of brick arch with a tension rod to resist horizontal thrust, and concrete filling over the arch ring.

Fig. 348 shows the hollow brick arch introduced by Sir William Fair-

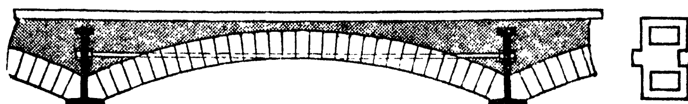


FIG. 348.—Early Form of Hollow Brick Floor Arch.

bairn, the beams being of cast-iron spaced 10 feet apart, the arches having the rise of 12 inches, and the hollow bricks the form shown by the section at the right hand of the drawing. An improvement to the

foregoing and other brick arches with exposed beams was introduced later in the form of fireclay blocks for casing the beams and at the same time constituting skewbacks for the arches. This device, illustrated in Fig. 349, may be regarded as the prototype of the numerous methods afterwards introduced for the protection of beams in floor systems of every kind.

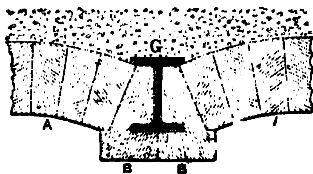
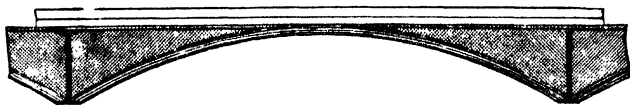


FIG. 349.

In this drawing, G is the girder, AA are parts of the brick arches, and BB are the fireclay casing blocks.

Concrete Floors.—Concrete used in fire-resisting floors may be plain or reinforced. Without reinforcement this material is practicable for short spans only, whether in the form of flat slabs or arches, owing to its cost and unnecessarily great weight. Plain concrete slabs are still used to a limited extent as a filling between floor beams and joists, and plain concrete arches are not unknown in basement vaults and similar construction. An early attempt to reduce the weight of plain concrete arches was made by Sir William Fairbairn, as illustrated in Fig. 350, where the intrados of the arch consists of a ¼-inch iron plate. This and


FIG. 350.—Early Form of Reinforced Concrete Floor Arch.

similar forms of construction, some of which are still employed, are open to the objection that the exposure of so much metal is a serious defect from the standpoint of fire-resistance.

Reinforced concrete is often applied in the form of arched girders or beams, but floor panels of this material are almost invariably constructed as flat slabs, which, although relatively thin, are capable of supporting heavy loads over long spans. The floor panels can either be moulded solid on the site or built up of short tubes of concrete or other refractory material, with narrow beams of reinforced concrete between the rows of tubes, or cement mortar joints between the tubes. Another method is to construct the floor of hollow reinforced concrete beams moulded in advance, laid side by side on steel beams and jointed by cement grout, as in the Seigwart floor system. Reinforced concrete floors composed of main and secondary beams and slabs acting with both series of beams can be reinforced in accordance with any of the systems described in Chapter XIV., and there are numerous varieties of steel meshing specially adapted to the reinforcement of slabs.

The choice of reinforcement is largely a matter of individual preference, and so long as a sufficient proportion of steel is provided and distributed as demanded by the principles of reinforced concrete design, the precise character of the reinforcement, whether patented or not, is immaterial.

The same remark applies in a general way to the many existing types of patented floors consisting wholly of reinforced concrete or partly of reinforced concrete and steel beams and joists. With regard to the latter, which are still more numerous than complete systems of reinforced concrete construction, the two most important points for consideration are the safety of the design and the efficiency of the protection afforded to the embedded metal or of the steel beams between the floor slabs, as the case may be.

The following illustrations relate to reinforced concrete flooring composed of plain or reinforced concrete tubes connected by narrow beams of reinforced concrete, and of tubular beams laid side by side and connected either by cement mortar or by narrow beams of reinforced concrete. Other types of flooring embodying reinforced concrete and tubes are described under the head of Terra-Cotta Floors.

Fig. 351 is an example of Mouchel-Hennebique hollow flooring with self-contained beams. The tubes in this case are 20 inches wide by



FIG. 351.—Mouchel-Hennebique Tubular Floor.

7 inches high by 24 inches long, and having been laid in rows on planks supported by light posts, they constitute moulds for the reinforced concrete beams moulded between the tubes, and centring for the reinforced concrete deposited above to form the floor surface. The tubes can be made of concrete with pumice or other light aggregate, and may be reinforced if considered necessary.

Fig. 352 shows part of an Armoured Tubular floor consisting of narrow beams moulded in advance, and placed, in rows about 10 inches apart,

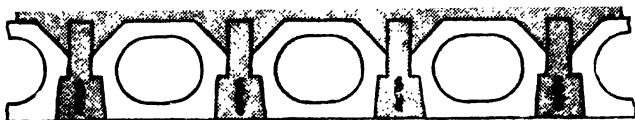


FIG. 352.—Armoured Tubular Floor.

on brick walls, or on the concrete haunching to steel girders. Between the rows are laid light concrete tubes 9 inches long, the whole forming a temporary platform which is sufficient to support the weight of workmen and materials for completion of the floor by the deposition of the top layer of concrete.

Fig. 353 is an example of U.K. flooring composed of tubular beams moulded in advance ready for placing upon steel girders. When the beams are in position, it is only necessary to grout the dovetail joints and to spread the top layer of concrete.

Being constructed entirely of fire-resisting material, with the exception of the embedded steel, reinforced concrete floors require no extraneous

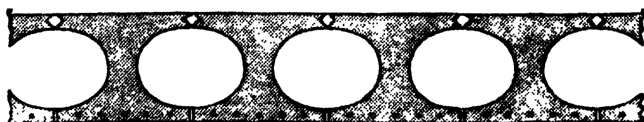


Fig. 353.—U.K. Tubular Floor.

protection, but in view of the superficial injury by fire and water that may result from a severe fire, an outer layer of fire-resisting plaster is often advisable.

Terra-Cotta Floors.—Terra-cotta blocks and tubes, and hollow porous bricks, are largely used between steel beams in the construction of floor panels, some designed as segmental and flat arches, and others constituting slabs. Several types recently introduced embody the combination of terra-cotta and reinforced concrete construction. Typical examples of terra-cotta floor construction are illustrated and briefly described in the following notes.

Segmental Arches.—Fig. 354 represents a segmental arch made with *side-construction* blocks, in which the interior air-spaces are parallel to

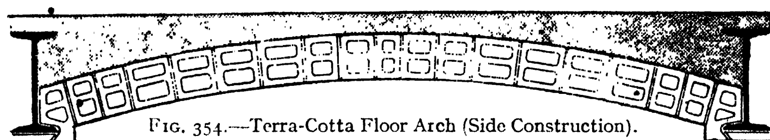


Fig. 354.—Terra-Cotta Floor Arch (Side Construction).

the supporting beams. This form of arch is strong and economical, but its use is chiefly limited to buildings where a flat ceiling is not essential. If desired, a suspended ceiling can be added.

End-construction blocks, in which the interior air-spaces are at right angles to the supporting beams, are not satisfactory for segmental arches, unless the latter are of uniform span and rise throughout.

Flat Arches: Side Construction.—Figs. 355, 356, and 357 are examples

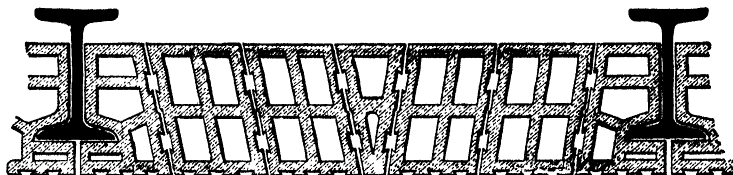


Fig. 355.—Terra-Cotta Floor (Side Construction).

showing three of the many different forms of blocks available for the construction of flat arches of this type. Fig. 355 shows an arch made up of blocks with bevelled joints and dovetailed grooves on the under side

for plastering. The radial joints in Fig. 356 are theoretically preferable, but the different shapes required for a single arch and for varying spans constitute a practical objection to this form of construction. The arch

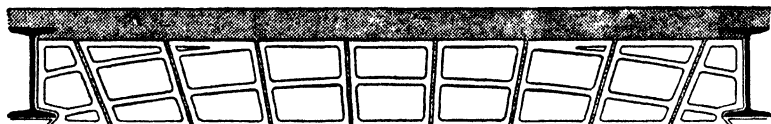


FIG. 356.—Terra-Cotta Floor (Side Construction).

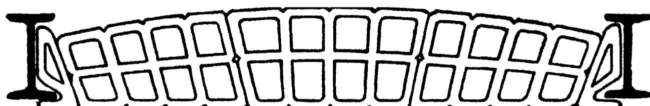


FIG. 357.—Terra-Cotta Floor (Side Construction).

illustrated in Fig. 357 can be constructed in spans up to 5 feet, and the trouble usually occasioned by radial joints is overcome by limiting the number of blocks.

Flat Arches: End Construction.—The chief advantages of end-construction blocks are that their compressive strength is greater longi-

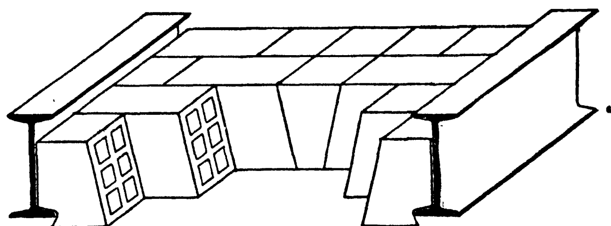


FIG 358.—Terra-Cotta Floor (End Construction).

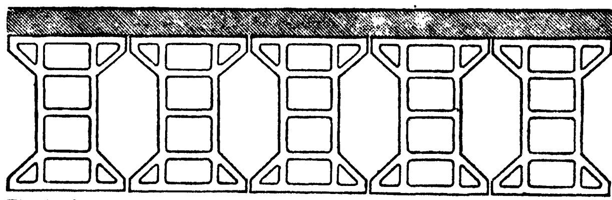


FIG. 359.—Terra-Cotta Floor: Part Cross-Section (End Construction Recessed).

tudinally than transversely, and that the disposition of the interior air-spaces permits tie-rods to be fixed without cutting any of the blocks. Fig. 358 represents a typical end-construction arch and the best method of breaking joints. Fig. 359 is a part cross-section of a floor panel composed of end-construction blocks with recessed sides affording accommodation for tie-rods and reducing the weight of the floor.

Flat Arches: Combined Side and End Construction.—The combination arch illustrated in Fig. 360 is typical of floor panels with side-construction skewbacks and a side-construction key. An end-construction key is always desirable on account of its greater strength. The chief recommendation of the side-construction skewbacks is the better protection they afford to the supporting beams. Although not so strong as the

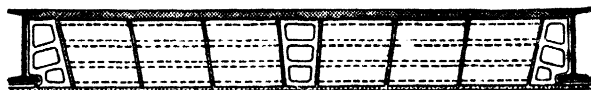


FIG. 360.—Terra-Cotta Floor (Combined End and Side Construction).

end-construction type, side-construction skewbacks can be made of ample strength by providing adequate sectional area and by introducing a sufficient number of partitions following the lines of thrust as closely as possible.

Tie-rods for Segmental and Flat Arches.—Tie-rods are necessary to take up the horizontal thrust of all terra-cotta arches. If all the spans in a floor system were equally loaded, tie-rods would only be required in the outer panels. As such equality never obtains in practice, tie-rods must be applied in every span, the spacing of the rods ranging from 4 feet to 7 feet, the area of metal being in accordance with the calculated thrust. In the case of segmental arches the tie-rods should be placed within the lower third of the supporting beams, or at the middle of the skewbacks. This arrangement will cause them to project below the soffite of the arch, where they are unsightly and difficult to protect efficiently against fire.

Suspended Terra-Cotta Tubular Floors.—In order to avoid the thrust of terra-cotta arches against walls and girders, various types of suspended floors acting as beams have been introduced. Fig. 361 shows an early floor of this type where triangular tubes of terra-cotta were placed on the

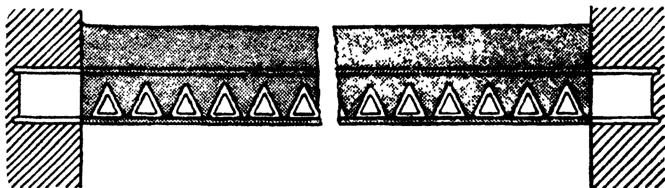


FIG. 361.—Terra-Cotta Floor (Early Tubular Type).

bottom flanges of rolled joists and the floor completed by concrete filling. Several floors essentially similar to this have since been introduced, the later types embodying various improvements, notably in the provision of protection for the metal by constructing the tubes so as to enclose the lower flanges.

Combined Terra-Cotta and Reinforced Concrete Floors.—Figs. 362 and 363 represent two forms of Kleine flooring composed of hollow porous brick

or terra-cotta blocks with closed ends, with joints of cement mortar thick enough for the reception of steel tension bands or rods, and completed by an upper layer of concrete. Fig. 362 includes part longitudinal and cross-sections of a floor with reinforcement in one direction only, and Fig. 363 similar sections of a floor with reinforcement in two directions. Fig. 364 is a part cross-section of a U.K. floor panel with hollow blocks of terra-cotta and wide joints of reinforced concrete. Figs. 365 and 366 show two types of the Dentile floor formed of hollow blocks and rein-

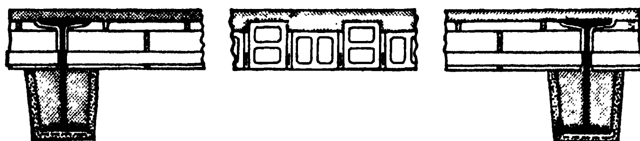


FIG. 362.—Kleine Floor (Reinforced in one Direction).

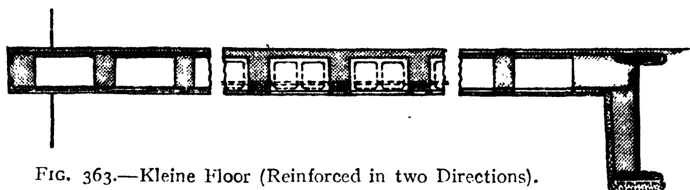


FIG. 363.—Kleine Floor (Reinforced in two Directions).

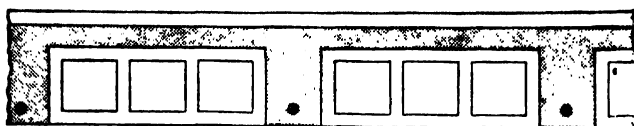


FIG. 364.—U.K. Terra-Cotta and Reinforced Concrete Floor.

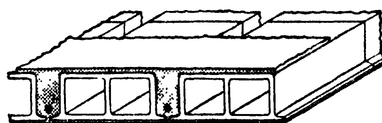


FIG. 365.—Dentile Floor (Reinforced in one Direction).

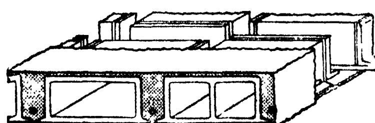


FIG. 366.—Dentile Floor (Reinforced in two Directions).

forced concrete, the former reinforced in one direction and the latter reinforced in two directions.

Suspended Ceilings.—In buildings where the floor beams project below the general level of the panels, it is sometimes considered desirable to add suspended ceilings, and the same course is frequently useful for the protection of combustible floors as well as for the sake of appearance and the reduction of sound transmission. From the point of view of fire protection, the best type of suspended ceiling is one formed of fire-resisting plaster applied to steel lathing attached to rods spaced at intervals of about 12 inches apart, the rods being clipped to the beams or

suspended from them by hangers of any suitable length. Fig. 367 illustrates an arrangement for the application of expanded steel as lathing for suspended ceilings.

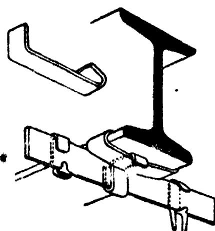


Fig. 367.

Partition Walls and Partitions.—For interior walls acting as structural elements carrying a share of the loads to be supported, the most satisfactory materials are brick, reinforced brick, and reinforced concrete, with an outer layer of fire-resisting plaster as a protection against superficial damage by fire and water, and for decorative purposes. Partitions which are required merely for the subdivision of areas can obviously be of much lighter construction than walls having to carry loads, but it is very important that they should be thoroughly efficient barriers to the spread of fire. The employment of timber studs, sills, and nailing strips in plaster partitions is both unwise and unnecessary, and openings of any kind are especially objectionable if fitted with combustible doors, window frames, and window sashes with ordinary glazing. Fire-resisting, or at any rate non-flammable, materials should be used for door frames, doors, window frames, and window sashes, and as additional precautions the windows should be stationary and filled with wired glass.

Reinforced Concrete Partitions are sometimes adopted in buildings constructed throughout in that material, but it is generally more convenient to employ other types of partitions which can be erected after the general framework; floors, and main walls have been completed.

Reinforced Brickwork, as described and illustrated in Chapter XIV., makes light and strong partitions, capable of effective resistance to fire and pressure from either side.

Terra-Cotta Blocks, made in thicknesses ranging from 2 inches to 8 inches, have been largely used for partitions. The porous variety is preferable to the harder qualities, and it is very desirable that the blocks should be moulded with some form of tongued and grooved joint, as illustrated in Fig. 368, in order to give additional stability to partitions formed of comparatively thin blocks. To construct terra-cotta partitions of adequate strength and fire-resistance, the blocks should not be less than 3 inches thick, the partitions must be built up from fire-resisting construction at each floor, and be securely fixed at the ceiling above.

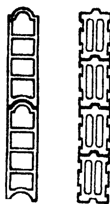


Fig. 368.

Slabs of Concrete, Plaster, and Special Compositions are made in great variety, their efficiency and strength in the form of partitions depending upon the fire-resisting properties of the material and constructive details.

Partition slabs are usually made with tongued and grooved or with dovetailed joints with the object of affording additional strength and rigidity. Partitions constructed of plaster on steel lathing secured to steel tension rods, or uprights consisting of light rolled sections, are useful for retarding the spread of fire. Such partitions may be either

solid or hollow. If the space between the two layers of lathing is filled in with concrete the result is a solid partition of great resistance, and one that may be relied upon as a thoroughly efficient protection. As in the case of other partitions, the use of timber should be avoided.

Roofing.—During recent years, reinforced concrete has been extensively employed in the construction of flat, arched, domed, and sloping roofs, thus offering an excellent substitute for the unprotected steel or timber principals and framing which have contributed so largely in the past to the disastrous effects of fires in buildings of all descriptions. A flat roof in reinforced concrete is designed and constructed precisely like a floor. In a pitched roof of small span the design is similar, but rafters and purlins take the place of main and secondary beams, while in a roof of large span, principals of the king post or other type are added. Arched principals, with reinforcement specially designed so as to take up the thrust at each end, are generally employed in arched roofs, and are sometimes constructed with the upper surface shaped to suit pitched roofs. If steel principals and framing are employed in connection with reinforced concrete, reinforced brick, or terra-cotta roof covering, the steelwork should be adequately protected against fire. Fig. 369 illustrates a system proposed by Mr. J. K. Freitag for protecting the steel trusses and framework of a roof with terra-cotta covering.

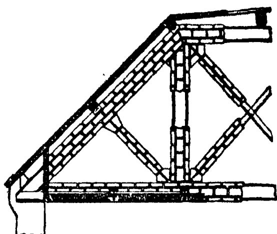


FIG. 369.—Roof Protection.

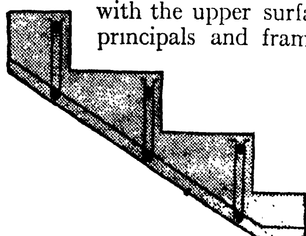


FIG. 370.—Mouchel-Hennebique Reinforced Concrete Stairs.

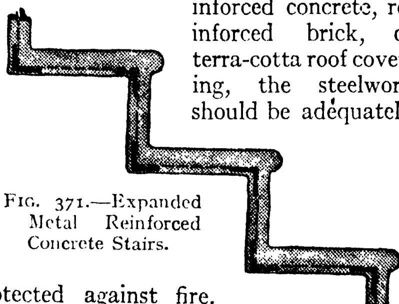


FIG. 371.—Expanded Metal Reinforced Concrete Stairs.

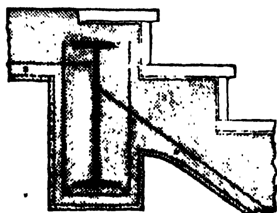


FIG. 372.—Reinforced Concrete Stairs, U.S.A. Government Printing Office, Washington.

Stairs.—In too many fire-resisting buildings, the designers have been content to employ stairs including unprotected, or inadequately protected, iron or steel, and stones which are incapable of withstanding great heat. Examples of fire-resisting stair construction in reinforced concrete are given in Figs. 370, 371, and 372. Reinforced concrete stairs can be faced with marble or any kind of tread, and permit the execution of artistic designs in a manner which is perfectly convenient and has the additional advantage of ensuring safety.

CHAPTER XVI

CARPENTRY

BY W. T. SWEETT

Introductory Notes.—Carpentry is the art of cutting, framing, and joining structural timber work, for a permanent or temporary purpose. The material may be wrought, moulded, or carved, but its chief function is to support or to form some part of the structure of a building.

The main timbers of roofs, floors, and walls are prepared and erected by the carpenter, as also are the centring for brick, stone, and concrete arches, and the shuttering and moulds necessary for works in concrete.

This chapter is divided into two main sections, one dealing with Joints and Fastenings, and the other with Beams and Floors. Timber Roofs are discussed in Chapter II. Part II., in one of a series of chapters devoted to various kinds of roofs and roof coverings. Other classes of carpentry work are considered in the chapters on Timbering Excavations, Shoring and Underpinning; Scaffolding; Centres and Moulds; and Partitions.

Precautions against Deterioration and Failure.—Care must be taken to guard against the deterioration and failure of structural woodwork from various causes, some of which are discussed below. Special care should be taken in the case of woodwork which is hidden when the building has been completed.

Decay.—The end of beams will decay if built into walls without sufficient air space for ventilation. Care must be taken to protect the bearing surfaces of the timber from moisture rising from the walls.

Use of Sapwood.—The sapwood of timber is usually attacked very early either by worms, when the atmosphere is dry, or by dry-rot when the atmosphere is humid. Moreover, sapwood is always a natural source of weakness.

Insufficient Seasoning.—Shrinkage and warping will affect structural stability if at all excessive. Parts may split or be weakened by the opening of shakes due to shrinkage, and the warping of a truss may set up leverage sufficient to break tenons and throw off the side of mortises. Timber should be sufficiently seasoned before use, and means should be provided by which straps and other fastenings may be tightened up when the work is fully loaded.

Twisted Fibre and Knots.—Where timber has been sawn from the log, there is the risk that twisted fibre or other peculiarity of growth may render some planks so cross-grained as to be quite unsuitable for load-

bearing purposes. Large knots in timber considerably reduce the effective sectional area upon which calculations of strength have been based.

JOINTS AND FASTENINGS

Classification of Joints.—Joints in carpentry may be classified as longitudinal, transverse, and framing joints.

Longitudinal joints are employed to lengthen timber, as in beams and members subject to compressive, tensile, or bending stress. They are applied in the forms of jointing described as *lapping*, *fishing*, *scarfing*, and *building-up*.

Transverse joints, alternatively termed *bearing joints*, are used for timbers subject to transverse or bending stress, and are embodied in methods of jointing such as *cogging*, *halving*, *housing*, and *notching*.

Framing joints are used to form all kinds of vertical framing, and have to resist shearing across and along the grain. *Mortise and tenon* and *dovetail* joints are familiar varieties of this class.

Fastenings.—The fastenings used in connexion with the above-mentioned joints, and in other branches of carpenters' work, include wedges, keys, pins, nails, screws, bolts, straps, shoes, and sockets.

Principles of Design.—The principles which should be adhered to in designing joints and fastenings are laid down by Professor Rankine as follows:

1. To cut the joints and arrange the fastenings so as to weaken the pieces of timber that they connect as little as possible.

2. To place each abutting surface in a joint as nearly as possible perpendicular to the pressure which it has to transmit.

3. To proportion the area of each surface to the pressure which it has to bear, so that the timber may be safe against injury under the heaviest load which occurs in practice, and to form and fit every pair of such surfaces accurately, in order to distribute the stress uniformly.

4. To proportion the fastenings so that they may be of equal strength with the pieces which they connect.

5. To place the fastenings in each piece of timber so that there shall be sufficient resistance to the giving way of the joint by the fastenings shearing or crushing their way through the timber.

LONGITUDINAL JOINTS AND JOINTING

Beams and struts are joined in the direction of their length by *lapping*, *fishing*, and *scarfing*.

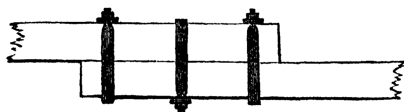
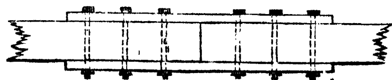


FIG. 373.—Lapping.

Lapping.—This consists in simply laying one beam over the other for a certain length, and binding them together with straps, as shown in elevation in Fig. 373, or, if the joint is to stand a tensile strain, with bolts.

Fishing.—The ends of the pieces are butted together, and an iron

or wooden plate or *fish-piece* is fastened on each side of the joint by bolts passing through the beam. Fig. 374 is the plan of a joint fished with wooden plates, and Fig. 377 shows one fished with iron plates. The bolts should be placed zigzag, so that the fish-plates and timbers are not cut through by more than one bolt hole at any cross-section.


FIG. 374.—Fishing with Timber Plates.

When subjected to tension, the chief strain comes upon the bolts (which are but slightly assisted by the friction between the *fish-pieces* and beam); these are loosened by the slightest shrinkage of the timber, and the bolts then press upon the fibres, crush them, and thus cause the joint to yield.

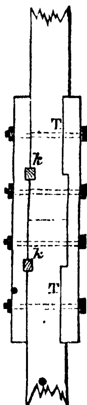


FIG. 375. Fished Joint showing Keys *kk*, and Tabling TT.

This dependence upon the bolts may be lessened by indenting or *tabling* the parts together, as at TT, Fig. 375, or by inserting keys, *kk*, but these arrangements decrease the section and strength of the beams. This is a very strong form of joint, but clumsy in appearance. It is useful for concealed work, or in rough and temporary structures, such as scaffolds.

When a beam is fished to resist compression, there should be plates on all the four sides. A fished joint is manifestly unsuited to resist a cross strain.

Tensile Strength of Fished Joints.—The strength of fished joints in tension depends:

(*a*) On the effective sectional area of the fish-plates being together equal in tensile strength to the effective sectional area of the beam.

(*b*) On the sectional area of the bolts being sufficient on either side of the joint to resist shearing. In practice the sectional area of the bolts may be taken as equal on either side of the joint to at least one-fifth the effective sectional area of the tie.

(*c*) On placing the bolts in such a way, and at such distances from the ends of the fish-plates and butting ends of the timbers, that they will not draw through by shearing out the wood in front of them.

(*d*) On giving the bolts such bearing-area as will prevent them from cutting their way through the timbers or the fish-plates. It is in this way that fished ties are most liable to yield.

Fishing Scarfed Joints.—Scarfed joints are often fished with steel or iron plates to assist the scarf (see Figs. 377, 378, 380, 381, and 382). These plates also serve to protect the wood from being crushed by the bolts. They are sometimes turned down at the ends into the timber, so as to assist it in resisting tensile stress. The indented ends should not be opposite to one another, as in Fig. 380, for in that position they cut into the timber at the same cross-section, and weaken it more than if placed as in Fig. 377.

Scarfing.—Many of the intricate forms of scarfed joints given in books will be found to be useless upon being tested by the following principles laid down by Tredgold:

When two pieces of timber are tabled together, as shown in Fig. 376, if a tensile strain in the direction of the arrow comes upon the joint, it is evident that it would tend to shear off the pieces *ahic* and *cifd* by sliding them along the grain; also to crush the ends of the fibres at *ci*; and, further, to tear the beams asunder at *bc* and *ik*. As "the weakest part is the strength of the whole," there would be no use in making *bc* wide enough to resist tearing if the piece *ahic* were so weak as to be dragged off, and *vice versa*. In such a scarf, then, the strength of *ci* to resist compression, that of *cifd* and *ciha* to resist shearing, and of *bc* or *ik* to resist tearing, should all be equal.

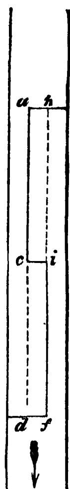
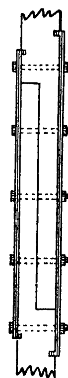


FIG. 376.

The bearing surfaces of indents which undergo compression should be at right angles to the direction of the compressing force: there is a temptation to make them oblique in order to hold the pieces together close, side by side. This is not an objection when the beam is exposed only to tension, but under compression the angular point of one piece tends to tear or split the other.

In the succeeding figures it will be noticed that the scarfs are frequently aided in their resistance to strains by the use of fish-plates, hard wood keys, and wedges. In applying these accessories to scarfs, their strength must be proportioned to that of the parts of the scarf itself. For example, the strength of the fish-plates (after being weakened by the holes for the bolts) must be equal to that of the beams to be united; and the resistance to shear afforded by the keys must be equal to that of the portion of the scarf on either side. From the above remarks it will be manifest that the form of the scarf should be varied to suit the nature of the strain it is to bear.

Scarf to resist Compression.—Fig. 377 shows in elevation a very simple form of scarf, evidently well adapted to resist compression. The bearing-surfaces are large, and perpendicular to the compressing force. Its form does not help it to resist tension. Under tensile stress it would depend entirely upon the shearing strength of the bolts to hold it together. Nor (unless the plane of the joint is placed vertically) is it adapted for resistance to transverse stress, which would bend the iron plates and tear out the bolts. A modification of this scarf is sometimes formed like that in Fig. 380, but if intended to resist compression only, the keys *kk* are not required. Any scarf containing oblique bearing surfaces is not adapted to resist compression, for the reason already given.


FIG. 377.—Scarf to resist Compression.

Scarf to resist Tension.—The scarf shown in Fig. 378 is sometimes used to resist tension, being made without the fish-plates, and having splayed angle or *sally*, formed at each end to hold the pieces together side by side.

The oblique surfaces of this scarf make it ill-adapted to resist compression, and the angles which receive the splayed ends are liable to be split by their pressure.

Scarf to resist both Tension and Compression.—The form of scarf shown in Fig. 379 is well adapted to resist both tension and compression, even independently of bolts and plates. It is evidently weak in cross-section, on account of the timber being so much cut away, and therefore it is not fit to withstand transverse stress. The wedges shown in the centre are most useful when bolts are to be added, in which case they bring the parts of the joint up to their eventual position before the bolts are inserted, so that there may be no transverse stress upon the latter.

FIG. 378.—Joint fished with Iron Plates, and scarfed to resist Tension.

FIG. 379.—Scarf to resist Tension and Compression.

Fig. 380 shows a modification of the last, in which the tabling is avoided, and the necessary resistance to tension is given by means of keys

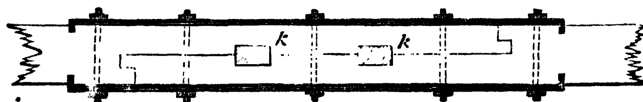


FIG. 380.—Scarf with Keys *kk* to resist Tension and Compression.

of hard-wood, *kk*, or pairs of wedges as shown in Fig. 379 may be used with advantage.

Scarf to resist Transverse Stress.—When a beam is subjected to transverse stress, its upper fibres are compressed and its lower fibres extended, as shown in an exaggerated form by the dotted lines in Fig. 381. In scarfing such a beam, therefore, the indents in the upper or compressed portion should be kept square and perpendicular to the pressure, while those in the lower or extended part may be oblique, as they have to resist tension only. The strength of the scarf is increased by inclining *ab* so as to have as great a thickness as possible at *cb*. The angle at *b* tends to hold the pieces together.

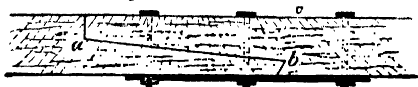


FIG. 381.—Scarf to resist Transverse Stress.

Scarf to resist Transverse Stress and Tension.—If in addition to transverse pressure, the beam is exposed to tension in the direction of its length, resistance to tension is afforded by placing a steel or wrought-iron plate over the joint on the lower side, as shown in Fig. 382.

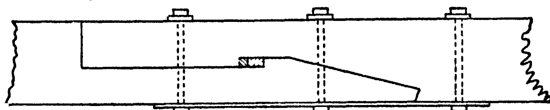


FIG. 382.—Scarf to resist Transverse Stress and Tension.

Scarfing Wall plates.—Fig. 383 shows the usual way of scarfing wall plates, purlins, and joints over bearing points.



FIG. 383.—Scarfed Wall Plate.

Rules for the Proportions of Scarfs.—The following practical rules were given by Tredgold for proportioning the different parts of a scarfed joint to resist tensile, compressive, or shearing stresses respectively.

(1) In Fig. 376, *cd* must be to *cb* in the same ratio as that of the shearing resistance to the direct cohesion of the material. In oak, ash, and elm, *cd* must be equal to from eight to ten times *cb*. In fir and other straight-grained woods *cd* must be equal to from 16 to 20 times *cb*.

(2) The sum of the depth of the indents should equal one-third the depth of the beam.

(3) The length of scarf should bear the following proportions to the depth of the beam.

	Without Bolts.	With Bolts.	With Bolts and Indents.
Hardwood (oak, ash, elm) . . .	6 times	3 times	2 times
Fir and other straight-grained woods	12 „	6 „	4 „

Building-up.—Curved ribs are sometimes formed of naturally curved timber, or timber artificially bent, and can be built up as described below.

Built-up Ribs.—To build up a curved rib, as illustrated in Fig. 384, several layers of plank on edge are placed together so as to break joint, and are united by bolts or wedges passing through them, the corners *abcde* being rounded. Rankine states that a built rib of this sort, properly constructed, is nearly as strong as a solid rib of the same depth, and of a breadth less by the thickness of one layer.

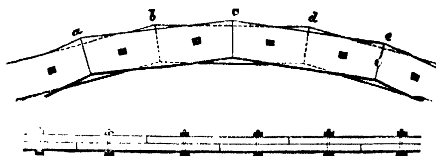


FIG. 384.—Plan and Elevation of Built-up Rib.

Laminated Ribs.—As shown in Fig. 385, laminated ribs are composed of layers of planks placed flatwise, breaking joint, and bolted together. They are easily made, and their strength, compared with that of solid ribs, is stated by Rankine as one is to the number of layers of which they are composed.

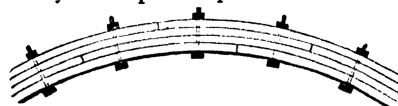
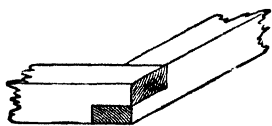


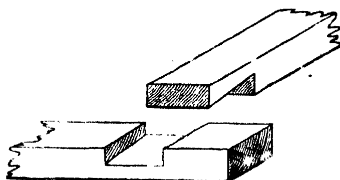
FIG. 385.—Laminated Rib.

TRANSVERSE JOINTS

Halving.—The simplest kind of halving is shown in Fig. 386. Half the thickness of each piece is checked out, and the remaining portion of one just fits into the check in the other, the upper and under surfaces of the pieces being flush. This is a common way of joining wall plates or

other timbers at an angle where there is not room to let the ends project so as to cross one another.

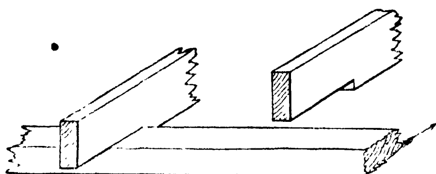

FIG. 386.—Halved Angle Joint of Wall Plates.

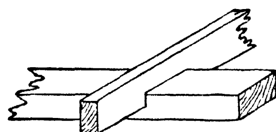

FIG. 387.—Bevelled Halving.

Bevelled Halving.—In this joint the surfaces of the checks are splayed up and down, as shown in Fig. 387. If the lower beam is firmly bedded, and the upper beam has a weight upon it, so that the surfaces are kept close together, their splayed form prevents the upper beam from being drawn away in the direction of its length, and greatly strengthens the joint.

Dovetail Halving—This form of joint is discussed under the head of Dovetails.

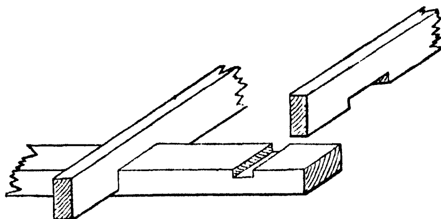
Notching.—A beam resting upon another may be notched, as shown in Fig. 388. Joists are sometimes thus fitted to wall plates, and where the joists differ in depth, the depth of the notches is also varied so as to bring the upper surfaces of the joists to the same level. It will be


FIG. 388.—Joists notched on to Wall Plate.


FIG. 389.—Joists notched out to Wall Plates, ends left on full depth.

seen there is nothing to tie the wall plate in toward the direction of the arrow. In other cases the end of the joist projects and is left on, as shown in Fig. 389; it then grasps and holds in the wall plate.

Double Notching.—If the notch is required to be a deep one, half of it may be taken out of each timber, as shown in Fig. 390. When each timber is notched to half its own depth, this joint becomes a form of *halving*.


FIG. 390.—Double Notching.

Dovetail Notching.—This is described under the head of Dovetails.

Tredgold's Notch.—The form of joint shown in Fig. 391 was recommended by Tredgold as a substitute for the dovetail, but is seldom, if ever, used in practice.

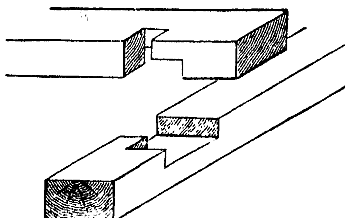


FIG. 391.—Tredgold's Notch.

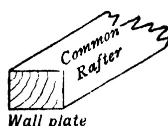


FIG. 392. — Bird's-mouth Joint at Parapet Wall.

Bird's-mouth Joint.—Fig. 392 shows the *bird's-mouth* joint, used to fit the common rafter to the wall plate for a roof having a parapet gutter. Fig. 393 is the form of bird's-mouth employed for finishing a roof with an eaves gutter, and Fig. 394 is the usual method of cutting and notching

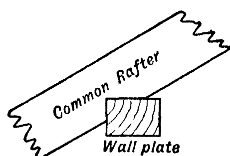


FIG. 393. — Bird's-mouth Joint for Roof with Eaves Gutter.

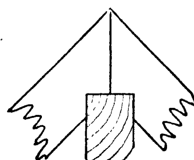


FIG. 394. — Bird's-mouth Joint for Roof with Low Ridge.

the top end of common rafters when the ridge is low, as in the case of roofs of the trussed ridge type.

Cogging.—In this form of jointing, also termed *corking* or *caulking* (see Fig. 395), the notch on the lower beam is only partly cut out, leaving uncut a piece or *cog* (like that of a cogged wheel). The upper beam contains a small notch only wide enough to receive the cog

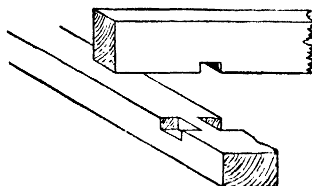


FIG. 395.—Cogged Joint.

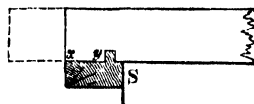


FIG. 396.—Joist cogged on to Wall Plate.

Joists or binders may thus be cogged on to wall plates: if they project beyond the wall plate, as dotted in Fig. 396, the cog may be made broader, but if they do not so project the cog must be narrow and kept

toward the inside, so that there may be sufficient substance of timber (xy) on the joist beyond the cog to resist the stress.

Such an arrangement takes a considerable piece out of the lower beam. If this is supported throughout, as in a wall plate, it is of no consequence, but if the beam spans an opening it is desirable to weaken it as little as possible. For instance, in cogging joists on to binders, or purlins on to principal rafters, the notches in the bearer are made very small, only about an inch or so in depth, and extending inwards about the same distance from the sides of the beam.

Cogging has the following advantages over notching: (1) The upper beam is kept at its full thickness at the point of support, and is therefore slightly stronger than when notched; (2) the cog gives the upper beam a hold on the lower one, even when its end does not project beyond the latter.

Housing.—This term is applied to a method of jointing, wherein the whole of the end of one piece of timber is let for a short distance, or *housed*, into another piece. The end of the rail is thus housed, as in Fig. 397, where the housing is shown in dotted lines.

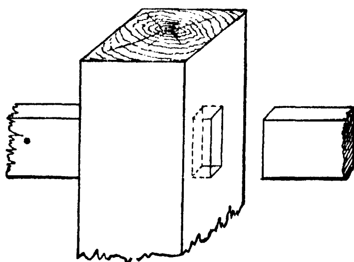


FIG. 397.—Housing.

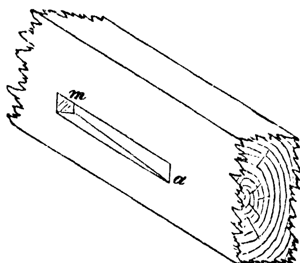


FIG. 398.—Chase-Mortise.

Chase-Mortising.—If a piece of timber has to be framed in between two beams already fixed, it is evident that the tenons could not be got into ordinary mortise holes. To enable the cross-piece to be fixed, a chase is cut, as shown in Fig. 398, leading to the mortise *m*, and the cross-piece is first held obliquely until the tenon enters the end of the chase at *a*, whence it is slid along into its place at *m*.

It may sometimes be necessary to make a vertical chase-mortise in a horizontal beam. This should, however, be avoided if possible, as it cuts through so many fibres. The mortise should be parallel to the grain of the timber.

Tusk Tenon.—This form of tenon is used for framing one horizontal beam into another, as in the case of a joist framed into a girder. It is designed so as to give the tenon as deep a bearing as possible at the root, without increasing the size of the mortise to such an extent as to weaken the girder unduly. This object is attained, as shown in Fig. 399, by adding below the tenon T the *tusk*, *t*, having a *shoulder*, *s*, which penetrates the girder to a depth equal to one-sixth the depth of the joist; above the

tenon is formed the *horn*, *h*, the lower end of which projects to the same extent as the tusk.

The tenon may be carried right through a narrow girder and pinned outside, as shown in Fig. 399; in thicker girders it may penetrate a distance equal to twice its own depth, and is pinned through the top of the girder, as in Fig. 400.

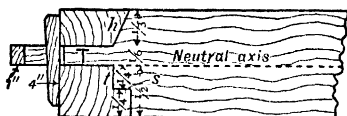


FIG. 399.—Tusk Tenon through Narrow Girder.

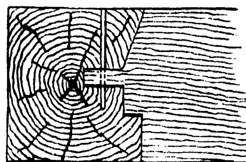


FIG. 400.—Tusk Tenon Joint with Thick Girder.

Position of Tusk Tenon.—The mortise should be on the upper side of the neutral axis, or central line, of the girder, as shown in Fig. 399, by which arrangement the tenon is in the compression area, and the tusk in the tension area of the girder.

In some cases the relative position of the girder and beam is determined by the space required by other parts of the framing, as, for instance, in a framed floor where more room must be left above for the bridging joists than below for the ceiling joists. This involves a higher position for the tenon, so as to bring it above the neutral axis of the girder. In every case it should be considered whether the girder or the joist can best afford to be weakened; if the former has an excess of strength, the tenon may be kept low, so as to avoid weakening the joist; but if the joist has more strength to spare than the girder, the mortise should be above the neutral axis of the latter, even though the tenon may be high up on the joist. In practice it more frequently happens that the joists, rather than the girders, have an excess of strength; so it is usual with carpenters to place the lower edge of the mortises on the neutral axis, and to let the position of the tenon on the joists be arranged to suit the mortises.

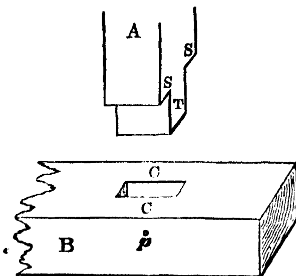


FIG. 401.—Mortise and Tenon.

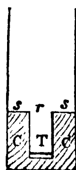


FIG. 402. Mortise and Tenon. Section.

FRAMING JOINTS

Mortise and Tenon Joints.—In addition to the two forms dealt with in the preceding section, several varieties of mortise and tenon joints are used in carpentry, as described in the following notes.

Common Tenon.—The simplest form of this joint is when a vertical timber A meets a horizontal beam B at right angles, as illustrated in Figs. 401

and 402. Here the *tenon* T is formed by dividing the end of A into three, and cutting out rectangular pieces on both sides, each equal to the part left in the middle. The *mortise* is a rectangular hole cut to receive the tenon. The sides, CC, of the mortise are called the *cheeks*; the surfaces on which the shoulders of the tenon rest are sometimes called the *abutment cheeks*. The springing of the tenon from the beam is called its *root*, *r*, Fig. 402; *ss* are the *shoulders*, and *p*, Fig. 401, the *pinhole*, which is generally placed at one-third the length of the tenon from the shoulder, and is in diameter equal to one-fourth the thickness of the tenon.

If the tenon reached exactly to the bottom of the mortise it would take its share of the pressure on the post, but it is difficult to make it do so with accuracy, especially as the mortise cut across the grain shrinks more in depth than does the tenon cut along the grain. Therefore in practice the tenon is generally made a little shorter than the depth of the mortise, so that the shoulders may bear firmly upon the sill.

When a horizontal beam is framed into another, and both are subject to a downward pressure, as in the case of joists framed into a girder, the position and form of the mortise and tenon will be determined by other considerations.

With regard to the position of the tenon on the joist, the lower down it is the less likely is it to be broken, because the mutual pressures of the butting surfaces above it protect it from transverse stress, and also because there is a greater thickness of timber above it to be bent, or torn off, under a breaking weight. The tenon must not, however, be so low down that there is not sufficient thickness of wood left below the mortise to support it.

It is evidently desirable for the strength of the tenon that it should be as large as possible, but in the ordinary form above described this would necessitate a large mortise, and very much weaken the girder. That form, therefore, is not adapted for joints intended to bear a downward strain, for which the *tusk tenon*, already described, should always be used.

Stub Tenon.—This is a very short tenon, sometimes termed a *joggle*, used where it is only required to prevent lateral motion—for example, to keep a post in its place upon a sill.

Dovetail Tenon.—As illustrated in Fig. 403, a dovetail tenon has one side splayed so as to form half a dovetail, the other side straight. The mortise is also splayed on one side, and is made rather wider than the tenon, which is placed in position, pressed well up against the dovetailed side of the mortise, and then secured by a wedge driven into the interval left on the straight side.

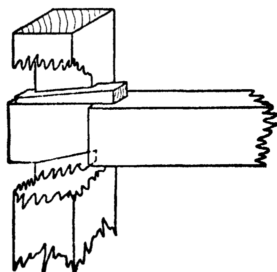


FIG. 403.—Dovetail Tenon: face-over tenon removed to show arrangement.

Housed Tenon.—Fig. 404 shows a tenon of this type, which is sometimes employed to give greater bearing strength to rails where fitted to

posts. When the posts and rails are of the same thickness the method shown in Fig. 405 should be employed.

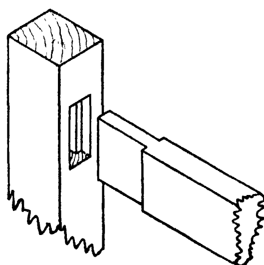


FIG. 404.—Housed Tenon.

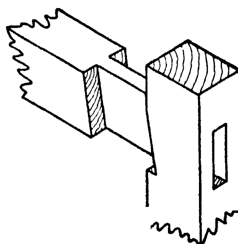


FIG. 405.—Vertical Mortise and Tenon.

Oblique Tenon.—When timbers are joined at other than right angles the tenon has to be modified in form. The cheeks of the mortise are cut down, as in Fig. 406, to the line *db*, so that while the tenon is retained to prevent lateral motion, the whole width of the beam itself presses against the abutment *ad*, by which a much larger bearing surface is obtained.

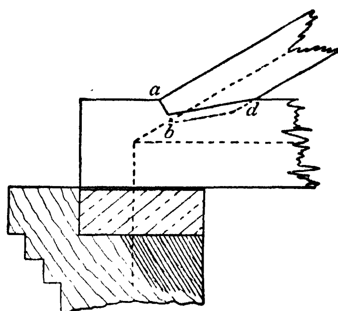


FIG. 406.—Oblique Tenon at junction of Principal Rafter and Tie Beam.

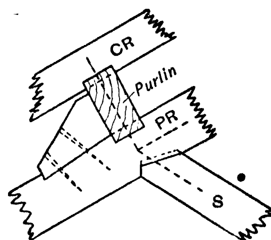


FIG. 407.—Oblique Tenon.

CR = Common rafter.
PR = Principal rafter.
S = Strut.

Figs. 406, 407, and 408 show how the abutments and the position of the joint are correctly obtained, the dotted lines in Figs. 406 and 407 being the centre lines of the various junctions and of the bearing surfaces.

Fig. 406 shows the joint as frequently constructed for the junction of a rafter and tie beam. Tredgold recommends that the depth *ad* should be greater than half the depth of the rafter, and at right angles to *db*. It is generally kept shallow from a fear of weakening the tie

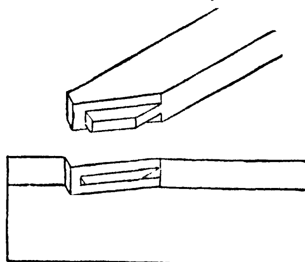


FIG. 408.—Oblique Tenon and Mortise for Joint between foot of Principal Rafter and Tie Beam.

beam ; except for this reason, the deeper *ad* is made the better, and it is often cut perpendicular to the upper surface or *back* of the rafter, as in Fig. 408. A modification of the same joint is shown in Fig. 409.

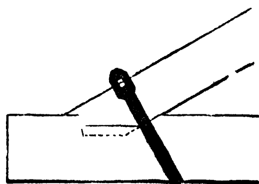


FIG. 409.—Oblique Tenon Joint at foot of Principal Rafter, with Strap.

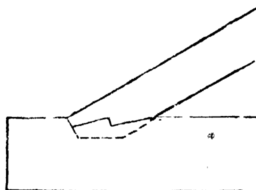


FIG. 410.—Oblique Tenon Joint with Double Abutment.

Fig. 410 shows a joint with a double abutment. This joint is very difficult to fit with accuracy, and is open to the objection that shrinkage of the timber may cause the whole of the pressure to fall upon one of the abutments. The joint is sometimes used when the angle is very oblique, and when there is consequently a large bearing surface.

Tenon Joint at Head and Foot of King Post.—In framing an inclined beam into either the head or foot of a king post a tenon joint is used. The head of the post should be enlarged, as at X in Fig. 411, so as to make the abutment nearly square to the inclined beam. If the head of the post is not large enough to afford the square abutment it may be cut as at Y, an arrangement which is usually preferred by carpenters. The tenon should be made, if possible, the whole depth of the inclined beam, but in cases where the top of the post is cut off close to the back of the rafter, the tenon is necessarily made narrower in order to leave some wood on the post above it to form a strong upper cheek to the mortise.

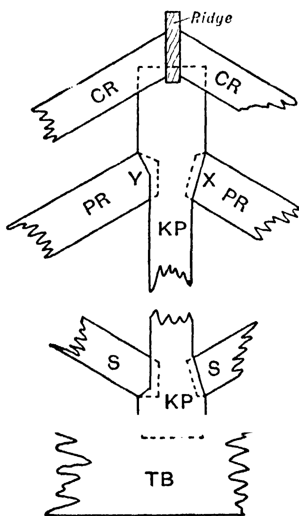


FIG. 411.—Tenon Joints for King Post.

CR = Common rafter.
PR = Principal rafter.
KP = King post.
TB = Tie beam.
S = Strut.

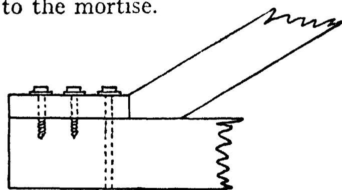


FIG. 412.—Abutment Joints for Temporary Work.

Abutment Joints in Temporary Work.—These are usually prepared as shown in Fig. 412.

Bridle Joint.—The bridle joint

may be regarded as a converse of the mortise and tenon joint. The simplest form, that for a post resting on a sill, is shown in Fig. 415, where it will be seen that a kind of mortise is cut in the post to fit the *bridle*, or projection, *bb*, left upon the beam.

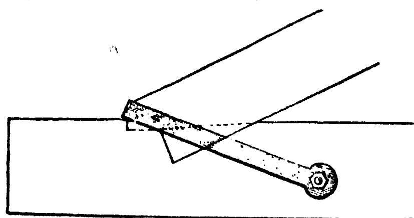


FIG. 413.—Bridle Joint with Strap at foot of Principal Rafter.

Figs. 413 and 414 show a bridle joint for the junction of the foot of a rafter with a tie beam, one illustration representing the completed joint with the addition of a *heel strap*, and the other showing the timbers detached so as to make clear the construction of the joint. A similar joint may be used where the head of the rafter meets the king post.

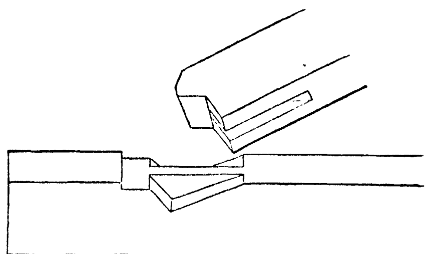


FIG. 414.—Bridle Joints for foot of Principal Rafter.

The bridle joint is only occasionally used in practice, although possessing the advantage that the parts can be seen into before they are put together, and can therefore be more easily fitted than those of the mortise and tenon joint.

The width of the bridle should not, if possible, exceed one-fifth that of the beam, otherwise the cheeks on each side of it will be weak, and liable to be wrenched off by a slight lateral pressure.

Dovetails.—Joints of this class are so called from the shape of the pieces cut to fit one another. They are objectionable in carpentry, because the wood shrinks considerably more across the grain than along it. The consequence is, that as *ab* (Fig. 415) shrinks more than *cd*, it is easily drawn partly out, and does not form a firm connexion. The joint

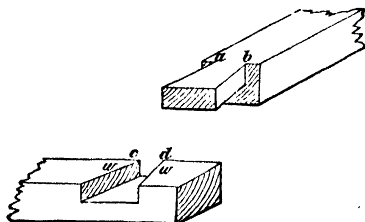


FIG. 415.—Common Dovetail Halving.

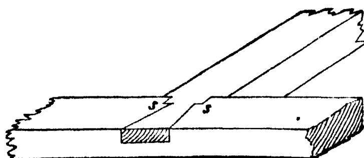


FIG. 416.—Shouldered Dovetail.

is, moreover, very weak at the angles *ww*, a defect which may be partly overcome by cutting shoulders to the dovetail, as at *ss* in Fig. 416. Dove-

tails are not liable to the first objection mentioned above when the grain in both pieces runs the same way, but in that case if the timber shrinks or is strained in the direction of its length, the cheeks are very liable to be split off.

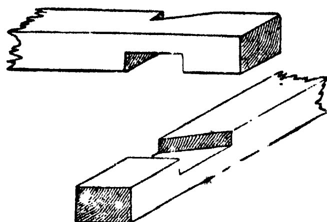


FIG. 417.—Dovetail Notch.

Dovetail Halving.—As illustrated in Fig. 415, this is a joint in which the dovetail is half the thickness of the piece upon which it is cut, and the notch to receive it is half the thickness of the other piece.

Dovetail Notch.—This is a good way of joining wall plates at angles (see Fig 417). The inside of the joint is dovetailed. and the outer side is left straight. Sometimes the joint is tightened up by a wedge driven in on the straight side. The defect of the dovetail is partly remedied by the grasp the projection of the upper beam has upon the lower beam.

JOINTS FOR SPECIFIC PURPOSES

Post and Beam Joints.—A post, either upon or under a beam, may be kept in its place by a joggle, or stub tenon ; but as the shoulders of the tenon may bear unequally, and thus reduce the effective strength of the post, the angular bridle joint (Fig. 418) is recommended by Tredgold as being more easily fitted. The bridle or projection left upon the beam is denoted by the letters *bb*. When the beam meets the post at right angles to the side of its head a vertical tenon may be used, as shown in Fig. 405, the housing in the post giving additional support to the beam. If the beam is at an inclination to the post, one of the several forms of oblique tenon joint may be adopted.

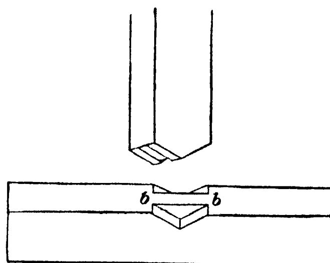


FIG. 418.—Bridle Joint between Post and Sill.

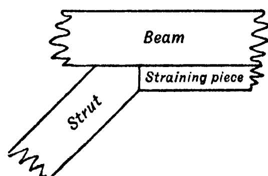


FIG. 419.—Strut and Beam Joints.

Strut and Beam Joints.—In these it is only necessary that the pieces abut firmly, as long as there is no force tending to make them slide off laterally. A plain mitre joint bisecting the angle is preferable to any more complicated form of jointing. Fig. 419 shows the usual method of forming this joint, which is sometimes completed by a cast-iron shoe formed to receive the ends of the timbers at the angle.

Tie and Brace Joints.—When two pieces of timber, meeting at an angle, are tied together (as in the case of two rafters united by a collar-tie, or of wall plates connected by an angle-tie), it is very important that the joints between the ends of the tie and the other pieces should not draw out or yield in any way. One method of forming such a joint is to cut out of the rafter or wall plate a notch of dovetail form, just deep enough to afford a bearing for the tie to rest upon, making a corresponding notch in the collar-tie, and securing the joint by a nail or pin (see Fig. 420). The dovetail in this joint is objectionable for the reasons already given.

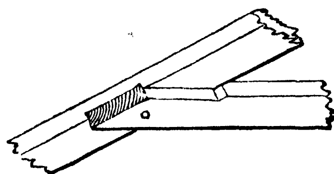


FIG. 420.—Dovetail Tie and Brace Joint.

Suspension Piece Joints.—Suspension pieces are used for supporting beams at one or more points. When adopted in a roof they hang from the point of junction of two rafters, and support the ends of the struts, as well as the tie beam. The rafters generally abut against the head of the suspending piece, as shown in Fig. 411. A better arrangement, in many cases, is to make the suspension piece in two thicknesses (the rafters being allowed to abut against one another), one on each side, as shown in Fig. 421, where RR are the rafters butting against one another, *ss* the suspension pieces notched upon the rafters and bolted together through the blocks, *bb*. The lower end of the suspension piece, supporting a pair of abutting struts and the centre of a tie beam, is shown in the same figure.

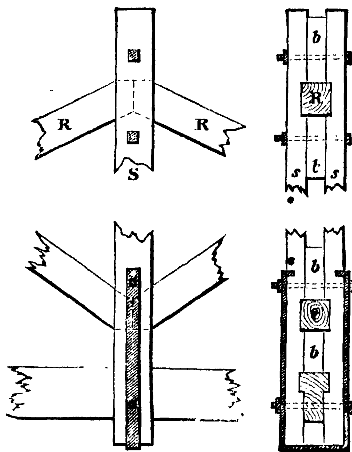


FIG. 421.—King Post formed with double Suspending Pieces.

FASTENINGS

Wedges.—In order to keep a tenon tightly fixed, wedges are driven in, as shown in Fig. 422, between the tenon and the sides of the mortise. The mortise should be slightly dovetail-shaped in plan, being wider on the side from which the wedges are inserted, in order to allow room for them to be driven in alongside of the tenon. When the wedges are on the compressed side of a beam they are of use in strengthening as well as in tightening the joint.

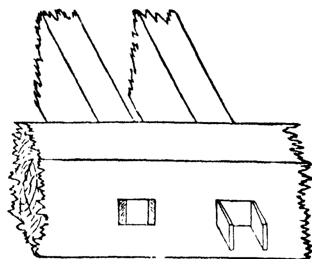


FIG. 422.—Wedged Tenon Joints.

Wedges are used in pairs for tightening up joints, being driven inwards so as to take up more room, and thus to force the parts of the joint together. When they are so used, great care must be taken not to drive them so hard as to leave the joint with a violent strain upon it.

Wedges are generally sawn out of straight-grained wood, and are dipped in glue or white lead before they are inserted.

Fox Wedges.—When a tenon is to be fastened into a mortise in a rail already fixed against a wall, or in any such position that the end of the tenon cannot be seen, it is secured by *fox wedges*, thus: A wedge is inserted in a saw-cut in the end of the tenon (Fig. 423). The mortise is

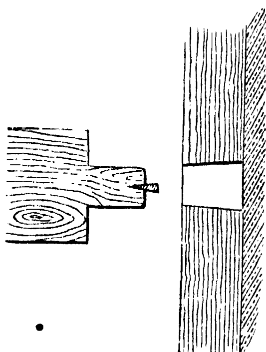


FIG. 423.—Single Fox Wedge.

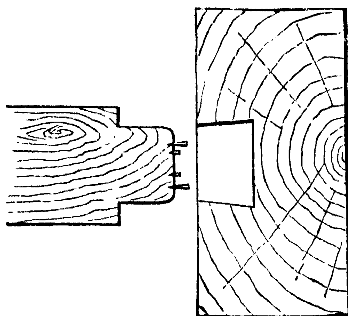


FIG. 424.—Fox Wedging.

made slightly wider at the back, and when the tenon is driven home the wedge entering it splits and spreads out the wood, and makes it fill up the mortise. With a single wedge there is some risk of splitting the tenon beyond the shoulder. This is thus avoided: Four or more very thin wedges are inserted (Fig. 424), the two outer ones being longer than the inner ones. As the tenon is driven home these in succession split off thin pieces which easily bend and therefore the splits do not extend too far. The wedges in the figure are rather short, but they should not be very long, as they would then be apt to be broken off in driving. The enlargement of the back of the mortise should be a little less than the total thickness of the wedges.

Keys.—A key is a wedge of hardwood and curled grain inserted in a joint, and driven gently home, so as to force the parts into the position they will eventually occupy, before inserting bolts, etc. (see Figs. 375 and 380). Without this precaution there would often be a permanent and injurious strain on the latter. In some cases keys also assist the joint in its resistance to the strain brought upon it (see Fig. 380). Keys should be slightly dovetail-shaped in plan, and carefully driven, so as not to injure the fibres of the beam in which they are inserted. The keys in scarfed joints are usually made one-third the depth of the timber.

Pins.—A pin is a peg of hardwood or iron inserted through the timbers forming a joint to prevent them from separating, or through a tenon to keep it from drawing out of the mortise. In the latter case the pin may

be through the mortised beam, or, if the tenon protrudes beyond the beam, the pin may be outside; care being taken to have a sufficient length of tenon beyond the pin to prevent the end from being shorn off by the pin if any strain comes upon it. Wooden pins should be made from pieces of hardwood, *torn* off from the baulk, in order that they may be of continuous fibre and uniform tenacity.

Drawboring is an arrangement for keeping the shoulders of the tenon quite tight up to the cheeks of the mortise, and for tightening pinned joints generally. The pin-hole is first bored through the cheeks of the mortise. The tenon is then inserted, and the position of the hole marked upon it, after which it is withdrawn, and a hole bored in it a little nearer the shoulder. The tenon is then again inserted, and an iron *drawbore* pin forced in right through the holes, so as to bring the shoulder up as tight as possible. The drawbore pin is then removed, and the wood pin is inserted. Although involving a constant and objectionable strain upon the pin and tenon, the foregoing procedure is nearly always followed in practice.

Nails.—Different kinds of nails are used for roughly and strongly connecting pieces of timber of moderate size, both in temporary and in permanent work.

Spikes are large nails used for heavy work.

Trenails are pieces of hardwood used, like iron nails, for forming strong joints, and occasionally, like pins, merely to secure joints formed in some other way. They are useful in positions where iron nails would rust and injure the work, and where copper nails would be too expensive. Trenails are generally of oak, cloven from the log, so that the logitudinal fibres may not be cut across. They are from $\frac{3}{8}$ to $\frac{3}{4}$ inch in diameter, and from 3 to 6 inches long, according to the thickness of the pieces they unite, and slightly tapered in form to facilitate driving.

Screws.—Various forms of screws are described in Part III. Screws are used in positions where the work is likely to be taken to pieces, as, for example, in centring, which has to be removed and reset in new positions as the work proceeds. The screws should, if used in damp places for securing work likely to be removed, be of copper or brass, otherwise they will rust and be difficult to withdraw.

Screws are useful also in cases where driving a nail would split the wood, for fixing iron work, and for other purposes where security is required without jarring the joint.

Bolts.—A bolt is a metal pin, one end of which is generally formed into a solid head, and the other end is screwed to receive a screwed nut. The head is usually square or hexagonal, so that it may be held by a spanner while the nut is tightened up at the other end. A *washer*, or flat metal disc with a hole in the centre, is placed on the bolt under the nut, partly to prevent the timber from being injured by the sharp edges of the nut when the latter is being screwed down, and partly to protect the timber from excessive pressure. A square plate of metal with a hole in the middle can be placed under the nut instead of a washer. Rectangular plates are often used under the head and nut of two or more bolts to strengthen joints, as described under the head of *fishing*.

Bolts are largely used to give additional security to joints, some forms of which depend upon them almost entirely for strength. The facility with which the nut can be tightened up, after the timbers have taken their bearing, renders a bolt extremely useful in carpentry. Care should always be taken to leave sufficient timber around bolts to prevent them from tearing through in the direction of the strain.

The proportions of the bolts used for any form of joint must be calculated in accordance with the stresses to be resisted, and it must not be forgotten that the holes bored to receive the bolts have the effect of reducing the effective area of the timber through which they pass. Washers and plates should be of thickness sufficient to enable them to maintain their form when under pressure, and of area sufficient to distribute the pressure so that it shall not exceed the permissible limit for the kind of wood used. In order that the permissible pressure on timber shall not be exceeded, it is often necessary to place a washer or plate under the head of a bolt.

Straps.—These are generally flat pieces of steel or iron, about 1½ to 2 inches wide, and varying in thickness according to the strength of the material and the stress to be resisted.

Straps are often used, instead of bolts, to strengthen or to form joints, and have the great advantage of not requiring holes, which reduce the effective area of the timber. They should be fixed, as nearly as possible, so that the stress may come upon them in the direction of their length. Cross stresses should be avoided as much as possible, but necessarily occur in branched *straps*, such as those described in Chapter II., Part II., on Timber Roofs.

Heel-straps are used to secure the joints between inclined struts and horizontal beams, such as the joints between rafters and tie-beams. They may be placed either (1) so as merely to hold the beams close together at the joint; or (2) so as directly to resist the thrust of the inclined strut, and prevent it from shearing off the portion of the horizontal beam against which it presses. Straps of the former kind are sometimes called *kicking straps*.

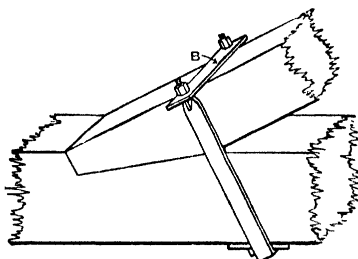


FIG. 425.—Strap for Joint between Rafter and Tie-beam.

Fig. 425 shows one form of strap for holding the foot of a rafter down to the tie-beam. The screws and nuts on its extremities are prevented from sinking into the wood by the bearing plate B, and by them the strap may at any time be tightened up. A check plate is provided, as shown, to prevent the strap from cutting into the under side of the tie-beam. If there is no ceiling, and the strap is therefore visible, the ends of the bearing plate are often rounded, instead of being left square as shown in the figure. The strap is sometimes reversed so as to bring the bearing plate below the tie-beam.

A somewhat similar form of strap is shown in Fig. 409. A bearing

plate or bar is passed through the holes in the strap across the back of the rafter, and the strap is tightened by wedges driven into the holes.

The strap shown in Fig. 413 is placed so as to take the thrust of the rafter, but is not capable of being tightened up. A bearing plate on the toe of principal rafter with screws and nuts may, however, be used with this form of strap. Straps of this description are sometimes placed so as to clip the rafter by a notch cut a few inches above the toe, thus partially holding it down as well as resisting its thrust.

Stirrups.—A strap supporting a beam or a heel strap of the form shown in Fig. 413 is termed a *stirrup*. Stirrups, such as that shown in Fig. 421, are sometimes formed with a bearing plate below the supported beam, and tightening screws similar in principle to those in Fig. 425.

Straps which connect suspension pieces with beams may be formed with a slot, containing gibs and cotters, by which the joint may be tightened, as described in Chapter II., Part II.

Tredgold's rule for the proportions of stirrups or straps supporting beams are as follows:

Thickness of Stirrup.	Width of Stirrup.	Unsupported Length of Beam.
$\frac{3}{16}$ in.	1 in.	10 ft.
$\frac{1}{4}$ "	$1\frac{1}{2}$ "	15 "
$\frac{1}{4}$ "	2 "	20 "

Shoes, Sockets, and Plates.—Various forms of shoes, sockets, and plates are used in connecting beams and struts.

Shoe for Foot of Rafter.—The foot of a strut or rafter may be received by a shoe instead of being tenoned into the beam (see Fig. 426).

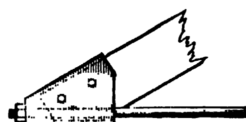


FIG. 426.—Iron Shoe with Tie-rod at foot of Rafter.

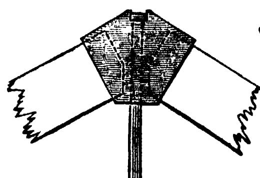


FIG. 427.—Cast-iron Head for Wooden Rafters.

Cast-iron Head.—Sometimes the tenons at the head of rafters, or the rafter heads themselves, are received in a cast-iron head, as in Fig. 427

Cap Plate.—Fig. 428 shows a cap plate coach screwed to the principal rafters, a method of fixing to be recommended for roofs of small span.

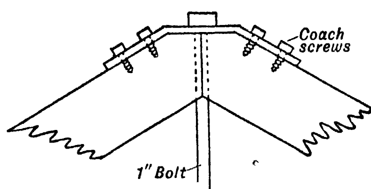


FIG. 428.—Cap Plate.

Tie-beam Plate.—All forms of tie-beam plate, formerly recommended for protecting the timber from damp in addition to affording support, are now considered objectionable, as frequently the first signs of decay appear where the timber is in contact with the iron plate.

BEAMS AND FLOORS

BEAMS

Under this head some special forms of timber beams are described and illustrated, ordinary floor beams and joists being dealt with in the succeeding section on Floors.

Flitch Beams.—A beam may be improved by cutting it down the middle, reversing the halves (called *flitches*), end for end, and bolting them together with the sawn sides outwards, small slips of wood being introduced between the flitches to keep them an inch or two apart, so as to allow a free circulation of air between them, see (Fig. 429).

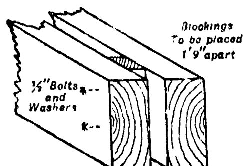
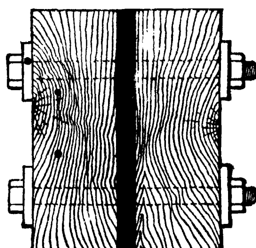


FIG. 429.

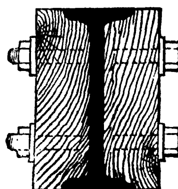
This arrangement causes the timber to season more quickly and thoroughly, as the pieces are smaller ; it also renders the heart of the wood visible, so that any decay can be detected ; moreover, the reversal of the flitches, end for end, makes the beam of equal strength throughout, which is very seldom the case in a long balk, as the top of a tree is generally weaker than the butt.

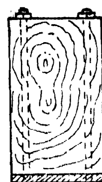

FIG. 430.

Iron Flitch Beam.—A beam thus cut down the middle is frequently strengthened by placing a steel plate or *flitch* between the halves, and bolting the whole together, as shown in the section Fig. 430.

The bolts are placed in the length of the beam so that the upper ones are over the centres of the intervals between the lower ones.

As shown in Fig. 431, a rolled girder is in some cases used instead of the steel plate.


FIG. 431.


FIG. 432.

Beams with Tension Reinforcement.—A beam may also be strengthened by fixing a steel plate with coach screws or bolts to the under side, as shown in Fig. 432.

Trussed Beams. — Beams have frequently been strengthened by a "truss" constructed within their own depth. Such a truss may be formed by splitting a balk longitudinally down the centre, and inserting between the flitches tension rods, as shown in Fig. 433. The ends of the tension rods pass through steel plates at the ends of the beam, and are there secured by nuts.


FIG. 433.

Cast-iron boxes are useful to protect the ends of the beam, especially when the latter are embedded in masonry, but they are often dispensed with; the upper corners of the beam being cut off at right-angles to the direction of the tension rod, and the nuts screwed up against a washer or plate. The middle of the rod bears against a steel or hardwood bar attached to the under side of the beam. It will be seen that a shrinkage in the depth of the beam frees it from the tension rod, which becomes slack and plays no part whatever; it can, however, be again brought into action by screwing up the nuts at its ends. In the meantime, however, the whole strain has come upon the timber.

FLOORS

Wooden floors consist of boards supported by timbers. The timbers of floors of upper rooms frequently have to carry a ceiling for the room below; they may also in workshops and warehouses be required to carry heavy goods or light machinery, which will therefore have to be considered in the construction of the floor. *Naked flooring* is the term applied to the timbers of the floor without the boards.

Classification of Floors.—There are three classes of floors, viz.:

Single floors,
Double floors,
Framed floors.

In all these floors the boards rest immediately upon pieces of timber called *bridging joists* or *common joists*.

N.B.—In the sketches illustrating the subject of Floors, the parts are marked with the distinctive letters given below.

Binders	B	Plastering	P
Boarding	*b*	Pugging	*p*
Bridging joists	*bj*	Strutting	*s*
Ceiling joists	*cj*	Templates	*tp*
Fillets for sound boards	*f*	Trimmers	T
Firrings	F	Trimming joists	*tj*
Girders	G	Wall plates	*wp*
Lathing	*l*		

Single Floors.—In single floors the common or bridging joists span the whole distance from wall to wall, and rest upon the wall plates or templates only (Fig. 434).

Advantages.—With a given quantity of timber, single floors are the strongest, cheapest, and simplest; they distribute their weight and load very equally over the walls upon which they rest, and hold the sides of the building together.

Disadvantages.—The disadvantages of single floors are:—1. When they are used for a span of more than 12 or 15 feet the bridging joists (unless of considerable size) are liable to bend or *sag*, and thus to crack the ceiling (if any) below. 2. They require a good deal of *trimming* to avoid resting the ends of the joists on flues, fireplaces, etc. 3. The joists bear equally on all parts of the walls, on piers and openings alike, and thus the jars upon the floor are communicated to the wall even at its

weak points. 4. They occasion the use of wall plates, which often have to be fixed in the wall, and are then objectionable. 5. They facilitate the passage of sound from the room below.

The last defect can be remedied or removed by *pugging*, and also by keeping nearly all the bridging joists clear of the ceiling, so as to have

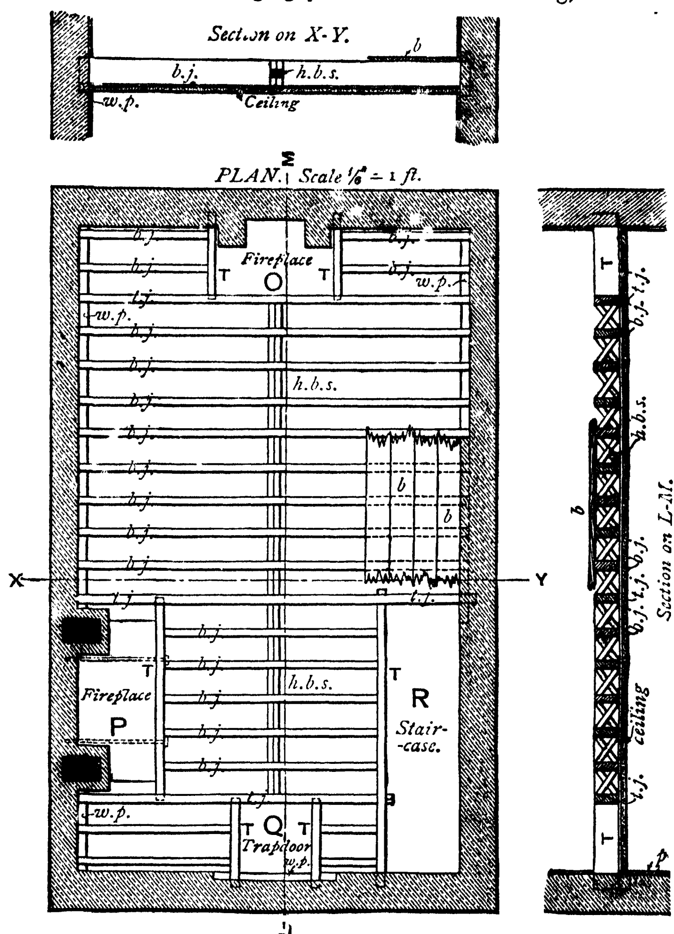


FIG. 434.—Plan and Section of Single Floor.

as few conductors for the sound as possible. This latter is, however, an expensive arrangement, as it renders ceiling joists necessary, an arrangement which is now seldom adopted.

In ground floors (see Fig. 435), where there is a space below and no ceiling, intermediate walls (*dwarf* or *sleeper* walls) or piers are built to support the joists at intervals.

Upper Floor.—Fig. 434 gives a plan and sections of a single floor. In this case there are no ceiling joists, the laths being nailed to the under side of the bridging joists, which are all of the same depth. At O the floor is trimmed parallel to the joists to keep clear of a fireplace, at P it is trimmed across the joists for another fireplace, at Q it is trimmed to form an opening for a trap-door, and at R for a staircase. Herring-bone strutting is lettered *hbs*; only a small portion of the floor boards are shown at *b*, in order that the joists and trimmers below may be visible in the plan.

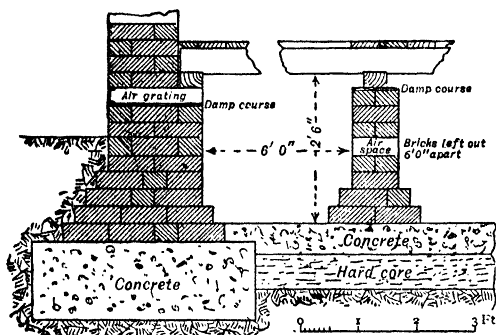


FIG. 435.—Part Section of Single Floor at Ground Floor level, with Supports.

Ground Floor.—Fig. 435 is the section of part of a single floor constructed just above the ground. The concrete under the floor itself is to prevent unwholesome exhalations from being drawn up from the subsoil into the room above. The damp courses are to prevent the damp from rising into the walls. No trimming is required for fireplaces on the ground floor, as the hearthstone is supported by dwarf brick walls called *fender walls.*

Double Floors.—In these the bridging joists, instead of spanning the whole distance from wall to wall, are supported by intermediate balks called *binders* (or *binding joists*), BB, Fig. 436.

The space between two binders is called a *case bay*, and that between the binder and wall a *tail bay*. Tredgold recommends that binders should be fixed from 4 to 6 feet apart, not more than 6 feet. They should be placed so that they may rest on the piers between the windows, not over the openings; they bear upon stone templates of a sufficient length to distribute the pressure.

The binders rest on stone templates, *tp*, and the trimming of the joists to clear a flue in the wall is shown at A. The method in which the floor is finished, with an oak border round the hearthstone, is also shown. A similar border is shown in section in Fig. 450. It is sometimes made, for economy, thinner than the floor boarding, which is checked out to receive it. The ceiling joists are omitted in plan to avoid confusion. It will be understood that they are attached to the under side of the binders, as shown in section, and run at right angles to their direction.

Advantages.—The stiffness of these floors prevents undue deflection, and secures the ceiling from cracking. They stop the passage of sound from the rooms below, and the massive binders are of great assistance to the walls of the building in tying them together. Moreover, if binders

are placed close to the walls to carry the ends of the joists, instead of using wall plates, all timber may be kept out of the masonry except the ends of the binders themselves.

Binding joists bring the whole weight of the floor and its load to bear upon a few points ; if the wall is weak and full of openings this is an advantage, for the binders may be carefully arranged so that their ends

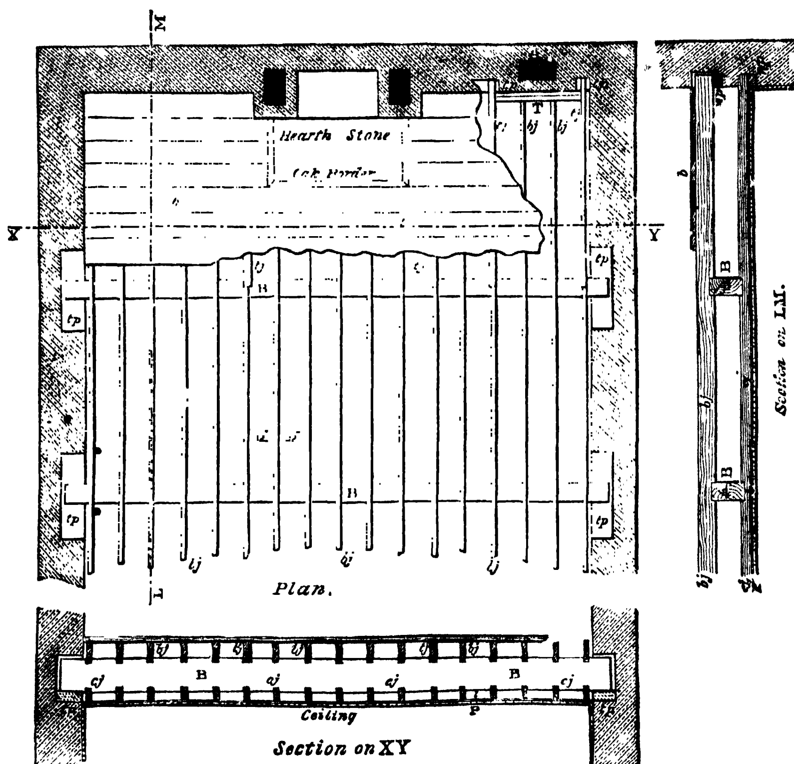


FIG. 436.—Plan and Sections of Double Floor.

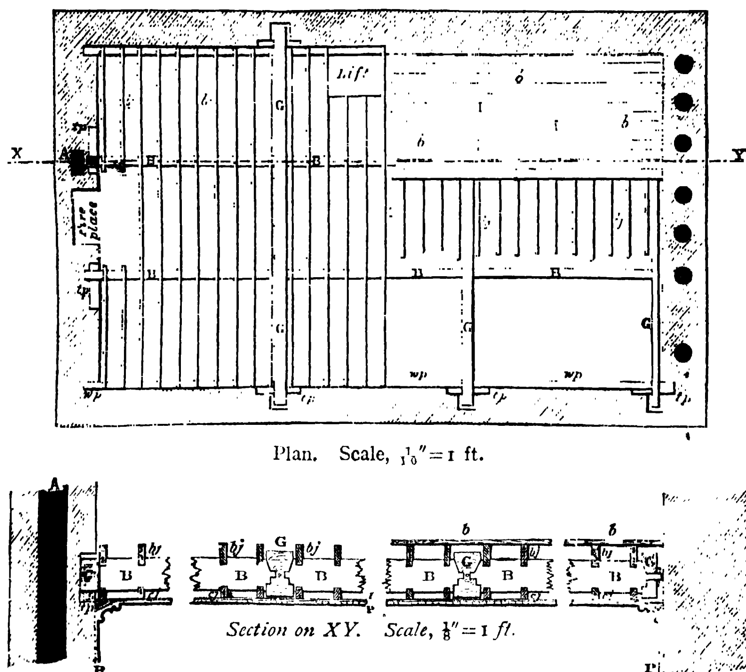
Scale, 6 feet = 1 inch.

fall upon the stronger portions of the wall, leaving the weaker parts unloaded.

Disadvantages.—Double floors are in some ways a complicated and bad form of construction. The bridging joists, instead of being merely supporters, add their own weight to be carried by the binding joists, and being superposed upon them, cause the floor to be very deep, which adds to the height of the walls and the cost of the building.

Framed Floors.—The bridging joists in these floors also rest immediately on binders, but the latter, in their turn, are supported by

larger balks or girders. Framed floors possess, in a still greater degree, the advantages and disadvantages attributed to double floors. The girders may be of any form or material selected after duly considering all the requirements of the case. If the girders are simple balks of timber, the binders are framed into them by tusk tenons. They should be kept as far as possible from the centre of the length of the girders, in order not to weaken them at the point where the strain is the greatest. The girders and binders should be as deep as possible, so that the floor may be stiff, not liable to shake or crack the ceiling below.



Plan. Scale, $\frac{1}{10}'' = 1$ ft.

Section on XY. Scale, $\frac{1}{8}'' = 1$ *ft.*

FIG. 437.—Plan and Section of Framed Floor.

Tredgold recommends that the distance apart of the girders should not exceed 10 feet; their position depends, however, on the plan of the building.

Fig. 437 represents a framed floor in plan and section. The girders rest upon templates, and the binders are framed into them as above described. The end of one of the binders, which is close to a flue in the wall at A, is protected against fire by a cast-iron shoe, C. Another way of effecting this would be to allow the end of the binder to rest upon a corbel projecting from the wall. One end of the floor is supported by a half-girder, in order that it may not rest upon the wall containing flues; if it were not for these the ends of the binders would rest upon the

wall. On the upper side is shown the trimming necessary for a lift. A great portion of the boarding is broken away to show the timbers below, and the ceiling joists are omitted in plan to avoid confusion.

When binders are tenoned into a girder they cut into and weaken it considerably, especially when, as is generally the case, the binders are opposite to one another (Fig. 438); to avoid this, iron stirrups are sometimes used to carry the ends of the binders, and so to leave the girder intact.

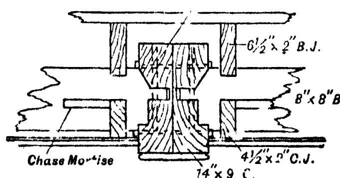


FIG. 438.

Floor Beams and Girders.—When the span of the floor is so great that timber beams of the required scantlings cannot be economically obtained, or are objectionable on account of their bulk or for other reasons, girders of other form and material may with advantage be used as before described.

Steel Beams.—Rolled steel joists, may with great advantage be used as a substitute for timber girders or binders, for they are less bulky and more durable.

Figs. 439 to 442 show different cases of the application of rolled beams or joists. In Fig. 440 a rolled beam, B, is substituted for the binder in a

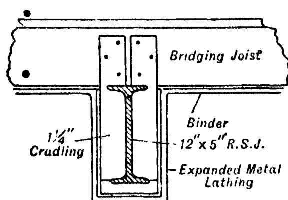


FIG. 439.

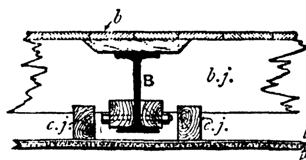


FIG. 440.

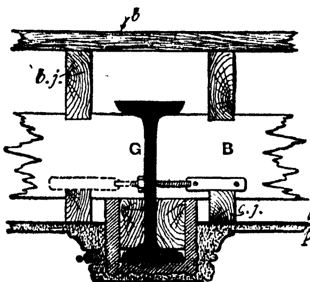


FIG 441.

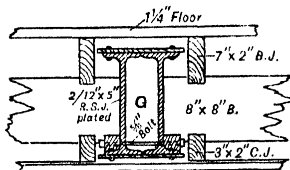


FIG. 442.

double floor. In Fig. 441 a rolled beam is substituted for the girder in a framed floor. In Figs. 439 and 441, the beams being too deep to be con-

tained within the floor, project beneath it and are concealed by plastering, which forms part of the panelled ceiling below.

Plate Girders.—When still stiffer girders are required they may be built up of R.S.J. and plates, as shown in Fig. 442.

General Remarks.—Girders should always be placed so as to have good supports for their extremities. Those intended to support floors should rest, therefore, on solid walls or piers, not over the windows or other openings. To ensure this, it is sometimes necessary to lay them obliquely across the room, but an inclined position should be avoided if possible. It is better to provide very strong templates over the openings to carry the girder and throw the weight well upon the piers. Rolled joists are often used for this purpose.

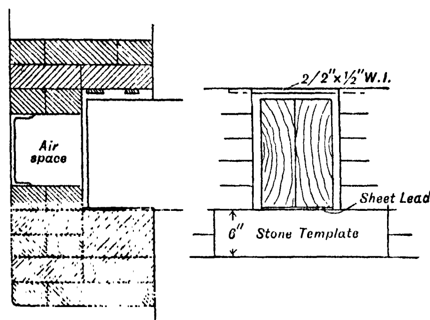


FIG. 443.

The ends of all timber girders should rest upon stone templates, and be perfectly clear of the masonry (Fig. 443). Girders should be weakened as little as possible by mortises or joints of any kind which cut into them, especially at or near the centre of their length, where the greatest strain comes upon them.

Wall Plates.—These are continuous, or are long pieces of timber built into or upon a wall to support the ends of joists or other bearers. They distribute the weight thrown upon them by the joists, and give the latter a hold upon the side walls, so that these are tied together. On the ground floor the wall plates generally rest upon an offset in the wall, as in Fig. 444.

Above, also, they may rest on an offset if there is a change in the thickness of the wall; or may be built into the wall, as shown in Fig. 445, great care being taken that there is a free circulation of air round the ends of the joists; or they may rest on corbels provided for the purpose, as in Figs. 446, 447, or upon a corbel-course, thus preventing all danger of decay by contact with the masonry and want of air.

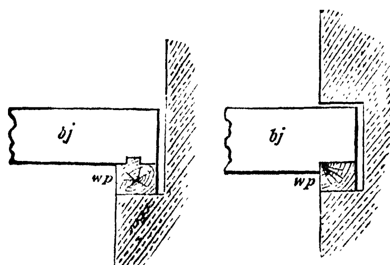


FIG. 444.—Joist on Wall Plate on Offset.

FIG. 445. Joist notched on Wall Plate built in.

The joists are either simply nailed on the wall plates, or *notched* (Fig. 443) or *cogged* (Fig. 446) upon them. If the joists are of unequal depths, the notches are varied in depth also, so as to keep the upper

surfaces of the joists in the same plane. Cogging gives the joists a good hold upon the wall plates, so as to tie the walls in, but it is seldom done.

Wall plates are sometimes dovetailed into each other where they meet at the angles of a building, but there are great objections to dovetails, and it is better that they should be halved and bolted. Wall plates should be in as long pieces as possible, and when two or more pieces are required to extend along the length of the wall they should be scarfed together.

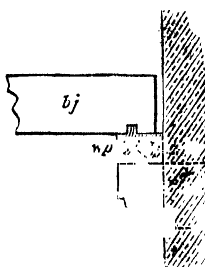


FIG. 446.
Wall Plates supported on Corbels.

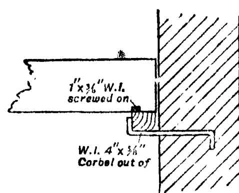


FIG. 447.

Rolled steel wall plates, with a raised rib running along their centre line, are sometimes used, and are free from many of the drawbacks of wooden wall plates.

Tredgold's Rule for Size of Timber Wall Plates :—

For a 20-feet bearing,	4½ inches	by	3 inches
,, 30 ,,	6 ,,		4 ,,
,, 40 ,,	7½ ,,		5 ,,

Templates.—Stone templates are often used instead of wall plates, and have the great advantage of being indestructible by fire or decay. The joists cannot, however, be economically fixed to them, which is a disadvantage. The templates should be of hard stone, and in lengths of at least 2 or 3 ft., so as to distribute the weight of the joist and its load over a wide bearing.

Iron corbels can be used to carry wall plates, as shown in Fig. 447.

Bridging Joists or **"Common Joists."**—These are generally laid about 12 inches apart "in the clear" (*i.e.* between the side of one joist and that

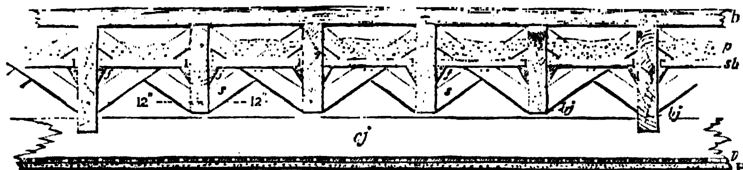


FIG. 448.—Section of Single Floor, showing Pugging, Sound-Boarding, and Herring-bone Struts.

of the joist next to it), or sufficiently near to prevent the deflection of the floor boards. In the best work, however, the joists are laid 12 inches from centre to centre as shown in Fig. 448, which is the section of part of a single floor with ceiling joists, supported by the deep joists at the ends of the figure. Only one joist in every four or five is

thus connected with the ceiling joists, in order to obtain a more rigid ceiling, and also that the points at which the sound can be conducted through the floor may be as few as possible.

Rough Rule for Depth of Joists.—The rule of thumb for the depth of common joists is to take half span in feet; to this number add 2 for the depth of the joist in inches.

Example.—For a span of 18 feet: Half this is 9, add 2, which gives 11 inches for the depth.

With the same quantity of timber, the deeper the joists can be made the stiffer and stronger they are. The depth can be calculated by the rules given above, or obtained from the Table on page 277. Joists should not be less than 2 in. wide, or they will be split by the nails holding the boarding, especially at the heading joints, where four nails come together. In a trenailed floor the joists should be wider. They should never be more than 3 in. wide if they are themselves to carry a ceiling (without the intervention of ceiling joists), as the lower surface of the joists causes a blank space behind the ends of the laths, which interrupts the key for the plastering.

Joists sometimes have a slight curve or *camber* in their length, due often to seasoning. In laying them this should be placed upwards to allow for the "sagging" or drooping which will take place after fixing. Any knots should be kept uppermost, *i.e.* in that part of the joists that will be under compression when they are loaded. The whole floor should be laid a little higher in the middle than at the sides of a room. This, however, is difficult to arrange. Joists are skew-nailed, cogged, or notched on to the wall plates, as before described.

Strutting.—Joists more than 10 ft. long should be strutted at intervals of about 6 to 8 ft., to make them stiff and to prevent them from turning over sideways. The struts also add greatly to the strength of the floor by causing the pressure on the joists to be transmitted from one to the other. To be really effective, strutting should be in straight lines along the floor, so that each strut may abut directly upon those adjacent to it.

Herring-bone Strutting.—This consists of small pieces, from 2 to 3 in. wide and 1 in. thick, inserted diagonally and crossing one another between the joists, as shown at *ss* in Fig. 448. They must not be split in nailing them; the holes for the nails must be bored, or two small saw cuts made in each end of the struts to receive them.

Solid Strutting.—Sometimes simple pieces of board at right angles to the joists, and fitting in between them, are used instead of the herring-bone strutting (Fig. 449), the joists being also bolted together with tension rods, adding stiffness to floors supporting great weight.

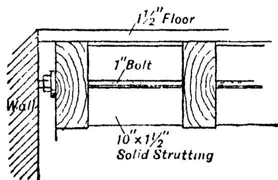


FIG. 449.

Pugging is plaster (coarse stuff), mortar, and chopped straw, or other mixtures laid upon boards fitted in between the joists of a floor to prevent the passage of sound or smell from the room below. It has the drawback of making the floor very liable to rot by preventing the circulation of air.

The *sound-boarding*, *sb* (see Fig. 448), to carry the pugging, *p*, is supported on fillets, *f*, nailed along the sides of the bridging joists, *bj*, about half-way down. The fillets are sometimes rectangular in section, about 1 inch by 1¼ inches, but are better if cut diagonally out of a piece 2 inches by 1¼ inches (see Fig. 448), as they then have a larger surface for nailing.

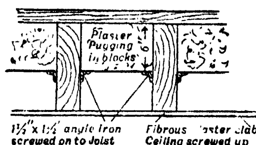


Fig. 450.

Specially made pugging blocks, Fig. 450, slag felt, or slag wool, are sometimes used. Sheet felt covering the top sides of the joists upon which the boards are nailed is recommended as a means for reducing the passage of sound. Felt or felt-paper over the boards and under the carpet have been used for the same purpose.

Trimming.—It often happens that on account of flues, fireplaces, or from other causes, it is inadvisable to let the ends of the joists rest on particular parts of the walls, and it is necessary that they should be trimmed. The arrangement of the trimming varies according as the joists are at right angles to or parallel to the wall in which the flue or fireplace occurs. In the former case (see Fig. 451), the joists are stopped short of the portion of wall to be avoided, and tusk-tenoned into a cross beam, T, called a trimmer, tusk-tenoned at the ends, and framed in between the two nearest bridging joists bearing on the wall, on each side of the portion to be avoided. The joists, *tj*, carrying the trimmer, are called *trimming joists*. As they have to carry more weight than the other bridging joists they are made wider.

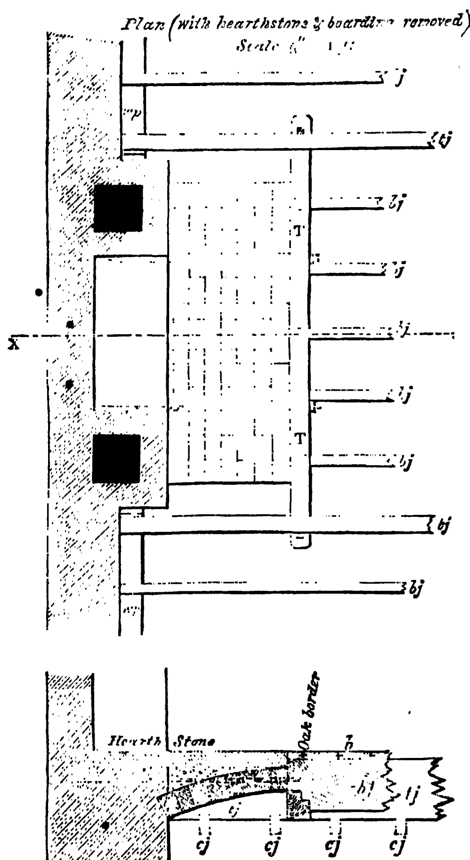


Fig. 451.—Section on XY.
Plan and Section of Chimney Breast and Hearth showing Trimming.

Tredgold's Rule.—To the width of the common joists add ⅛ of an

inch for every joist carried by the trimmer, and that will give the width of the trimming joists. The trimmer should be calculated by the same rules as binding joists (see page 262). This rule refers to the ordinary case in which the joists are all of the same depth, as in Fig. 434. When the trimming joists are deeper than the others, they need not be so wide in proportion.

Fig. 451 shows five joists trimmed to avoid a fireplace. A small *trimmer arch* is turned from the wall to the trimmer to carry the hearthstone. The length of this arch may with advantage be equal to the full width of the chimney breast, and it should in any case be at least 27 inches longer than the width of the opening of the fireplace, so as to support the hearthstone, which is 18 inches longer than the width of the opening, and to leave room besides for a cradling piece 4½ inches wide at each end, to support the oak border and the ends of the floor boards.

In some cases a filling-in piece is fixed between the trimmer and the wall to support the ceiling joists under the arch. This construction is, for some reasons, objectionable, for it requires a corbel or plate in the wall to support the end of the filling-in piece; and in the illustration given (Fig. 451) it is also unnecessary, for the ceiling joists can be fixed to the trimming joists as shown, and require no support between them. If, however, there are no ceiling joists, the filling-in pieces are necessary to support the laths for the plaster of the ceiling.

When the hearth to be supported is wide, and the depth of the floor is not sufficient to afford room for the rise of an arch such as that in Fig. 451, then the trimmer arch may be continued past the crown, as shown in Fig. 452, springing on one side from the chimney breast and on the other from a splayed fillet nailed against the trimmer or trimming joist to form a skewback.

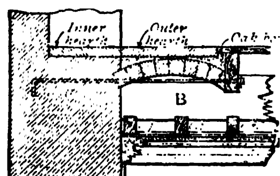


FIG. 452.

When the joists are parallel to the wall in which a fireplace occurs, the trimmer arch is turned against the first continuous joist (in this case called the *trimming joist*), and short trimmers, T, are inserted to carry the trimmed joists between that joist and the wall, in the same way as shown in the trimming for the fireplace in Fig. 434. The thrust of the trimmer arch is sometimes counteracted by steel rods built into the wall, as shown in dotted lines. They are more useful when the joists are parallel to the fireplace, in which case the trimming joist against which the arch abuts requires support against bending laterally.

Fig. 436 shows two joists trimmed to avoid the flue at A. In Fig. 434 is shown the trimming necessary for a trap-door in the floor, and in Fig. 437 a trimming for a lift. Openings for stairs are trimmed in a similar manner (see R, Fig. 434).

Floor Boards.—These are laid in several different ways.

Plain Jointed.—The boards are simply laid side by side as close as possible (see Fig. 453), a nail or generally two being driven through the

boards into each joist. The inevitable shrinkage of the boards, as at A, will cause openings through this description of floor.

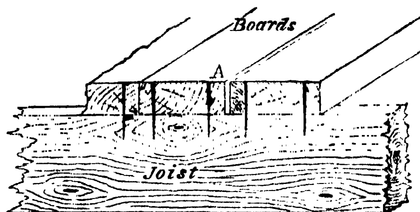


FIG. 453.—Plain Jointed Flooring.

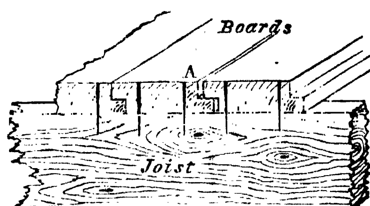


FIG. 454.—Rebated Flooring.

Rebated.—The section, Fig. 454, explains itself. Here a considerable shrinkage may take place, as at A, without causing an opening between the boards throughout their depth, but the joint is not an economical one, and is seldom used. *Fillistered* is another name for the joint shown in Fig. 454.

Rebated, Grooved, and Tongued.—One board can first be nailed, as shown in Fig. 455, and then the other board, upon being slipped into it, will be kept down by the form of joint. Thus the nails are prevented from appearing on the surface of the floor, which is sometimes desirable.

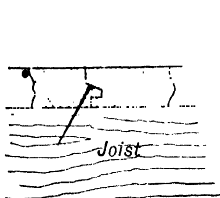


FIG. 455.—Rebated, Grooved, and Tongued Flooring.

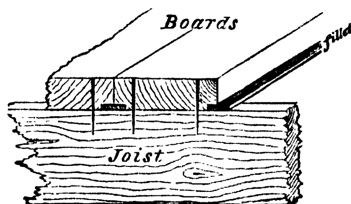


FIG. 456.—Rebated and Filleted Flooring.

Rebated and Filleted.—A rectangular rebate is cut out along the lower edges of the boards, as in Fig. 456, and the space filled in with a slip, or *fillet*, generally of oak or some hard wood, about $1\frac{1}{4}$ or $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. in section. It will be seen that any opening caused by shrinkage is covered by the fillet, and the floor must be worn down nearly through its whole thickness before the fillet is exposed, so that the joint is an economical one and is easily repaired.

Ploughed and Tongued.—A narrow groove is cut in the side of each board, and an iron or wooden tongue inserted (Fig. 457).

It will be noticed that this shares some of the advantages of the filleted joint, but the tongue is sooner laid bare when the floor is much worn. The tongue should be kept lower than the centre of the thickness of the boards, so that as much wear as possible may be got out of them before it is exposed. When wooden slip feathers are used they should

have a coat of paint, and iron tongues should be painted two coats, or galvanised to prevent their rusting, swelling, and splitting the wood.

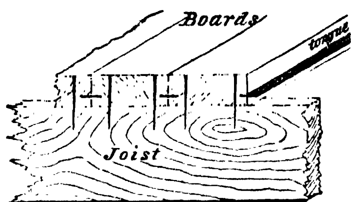


FIG. 457.—Ploughed and Tongued Flooring.

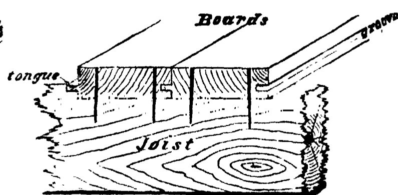


FIG. 458.—Grooved and Tongued Flooring.

Grooved and Tongued.—In this joint (Fig. 458) the tongue is worked upon one board to fit the groove cut in the other. This is not an improvement on the joint last described ; the tongue is necessarily thicker, and thus causes a thinner piece of wood to be left above the groove. This rots and flakes away if the floor is often washed.

Dowelled.—Small oak dowels are fixed along the edge of one board to fit into holes in the other (see Fig. 459) The dowels should not be over the joists, but in the spaces between them, so that the edges of the boards are held down and kept flush, at short intervals throughout their length, by the nails at the joists, and by the dowels between. Dowelled floors show no nails on the surface ; only one edge of each board is nailed obliquely, the other being kept down by the dowel.

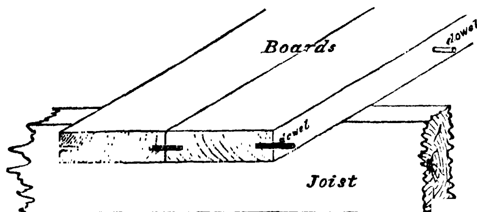


FIG. 459.—Dowelled Flooring.

Of the joints above described, those illustrated in Figs. 453, 454 are used chiefly for inferior floors ; those shown in Figs. 456, 457 for warehouses or barracks ; those in Figs. 458, 459 for ordinary floors of a high class ; and that in Fig. 455 for very superior floors. The joints in Figs. 454, 455, 458 necessitate the use of a larger quantity of boarding to cover a given surface than when the other joints are adopted.

Headings.—The boards in floors are seldom long enough to go right across the room. In such a case the joint between the end of one board and the next is called the heading joint. Headings should always fall upon joists, and break joint with one another in plan.

Square Heading.—In this the ends of the boards simply butt against one another, similarly to the side joints in Fig. 453.

Splayed or Bevelled Heading.—The ends of the boards are splayed to fit one another, as shown in Fig. 460.

Tongued Heading.—The ends of the boards are cross-grooved, and

laid with a cross-grain wood, or a metal tongue or similar to that shown for the side joints in Fig. 458.

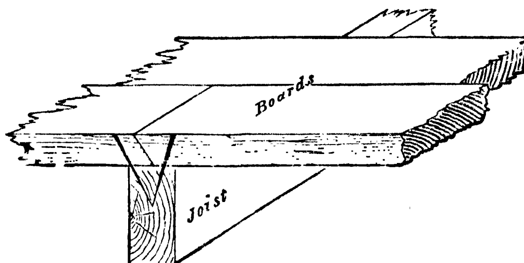


FIG. 460.—Splayed Heading.

Rebated and Tongued Heading is formed in the same way exactly as the joint shown in Fig. 455, and has the advantages mentioned.

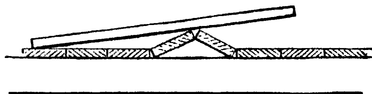
Broken Joint Floors.—Sometimes in very common work boards of unequal width are used, so that there are breaks in the longitudinal joints.

Straight Joint Floors.—The usual practice is, however, to have the floor boards gauged to the same width, so that their longitudinal joints form straight lines from end to end.

General Remarks on Floor Boards.—Floor boards should be brought on to the ground prepared and planed, generally by machinery, as early as possible after the building is commenced, so that they may be thoroughly seasoned before they are required to be laid. Blocks and boards for floors should be *rift sawn*, *i.e.* at right angles across the annular rings; by so doing trouble arising from shrinkage is reduced to the minimum, and shelly or splintering boards are avoided. The best floors are those laid with narrow boards (from batten widths down to strips of 3 or 4 in. wide), as the shrinkage in each is less, and the joints can be kept tighter.

Folded Floors.—Floor boards are generally jammed tightly together as they are laid, by means of flooring cramps, but in common floors they are sometimes laid folding, thus:—

Two boards are laid and nailed at a distance apart little less than the width of three or four boards. These are then put into the space, and forced home by laying a plank upon them, and jumping upon it (see Fig. 461). The boards thus laid together are often of the same length, so that their heading joints fall into one line, and are not properly broken.


FIG. 461.—Laying Folded Flooring.

Floors in Two Thicknesses.—In very superior floors two layers of boards are frequently used. The lower layer consists of ¾-inch deal, carefully laid and nailed on to the joists in the usual way. When it is down, the grounds, joinery, skirtings, etc., are fixed, and the plastering

completed. After which, the upper layer, consisting of narrow strips 1 or 1¼ inches thick, which may be of wainscot oak or of some superior wood, is fixed with dowelled or other secret-nailed joints, or glued.

Nailing Floor Boards.—The position of the nails, in the various forms of joint, is shown in the figures.

Flooring brads (Fig. 462) are generally used for securing the boards to the joists. They are flat-sided nails, which are easily driven in parallel to the grain of the boards without danger of splitting the wood; their heads, being parallel with the grain, can be punched below the surface so as to admit of the floor being planed.



FIG. 462.



FIG. 463.



FIG. 464.

They hold better than clasp nails (Figs. 463 and 464), and the heads of the latter disfigure the surface of the floor. Clasp nails or oval brads must, however, be used for edge or secret nailing, as brads would break under the cross strain brought upon them in that position. Holes must be bored for wrought clasp nails or they will split the wood in driving—the labour of boring is saved where cut nails are used.

When the heads of the nails are concealed, as in Fig. 455, the floor is said to be *secret-nailed.* This may be effected in the joints shown in Figs. 457 and 458, by driving the nail obliquely through the edges of the boards, taking care to clear the tongue or feather. Secret-nailing is always advisable for polished oak floors, or when the boards are very narrow, as, in the latter case, there would otherwise be a great many nail-heads in the surface.

Screwing down Floor Boards.—Occasionally, especially in oak floors and where boards may have to be removed to get at gas pipes, etc., the boards are screwed down. For oak floors the hole should be countersunk, or a piece taken out about ½ in. deep above the head of the screw, and filled in afterwards with pieces of oak to match the floor; this is called *pelleting* (see Fig. 465).

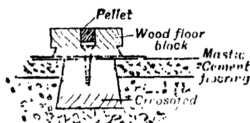


FIG. 465.

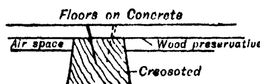


FIG. 466.

Fixing wood floors to concrete is usually carried out as shown in Fig. 466; creosoted dovetailed fillets are embedded in the concrete and the floor boards nailed or screwed to them.

Parquet Floors.—In floors of this class the surface is formed with small pieces of wood, inlaid to a pattern. They are more the work of a

joiner than of a carpenter. The parquet material is usually about ¼ to ⅜ in. in thickness, and is glued to a floor laid in the usual way, which is known as a *sub-floor.* These are sometimes laid diagonal, counter-joists being inserted to take the ends of the boards, or the joists may be filleted, the boards being laid between and flush with the joists. Parquet is also laid on deal sub-floors as carpet surround.

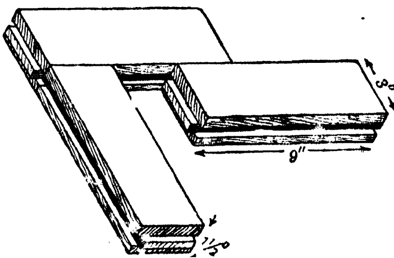


Fig. 467.—Wood Block Flooring.

Block Floors are laid in thicknesses from ⅞ to 1½ in., usually on concrete sub-floors, with mastic, the blocks being dowelled tongued and grooved, or V-grooved. (Fig. 467 shows grooved and tenoned blocks prepared by Messrs. Goddard & Sons, Farnham, Surrey.)

Fixing blocks, shown in Fig. 468, are creosoted and bedded in concrete at 3 feet centres, and the floor blocks coming immediately over them are screwed down, the screw holes being pelleted as in Fig. 465. The dotted lines, Fig. 468, show the longer fixing blocks used around the walls for fixing the borders.

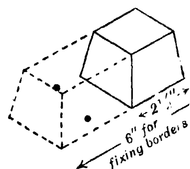


Fig. 468.

Jointless Floor Coverings.—Several compositions are now used. They are laid in a plastic state, and are applied equally well to new or old floors of any material, and have much to recommend them, being used extensively in hospitals and public buildings; amongst others may be mentioned "Ebernite," Jos. J. Ebner, Stewart Street, London, E.; and "Turpolith," Turpins Company, Ladbroke Grove, London, W. An illustration of the finish of these floors is given, Fig. 469.

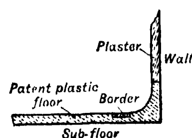


Fig. 469.

General Remarks on Floors.—The timbers that carry the weight should, as a rule, be laid the narrowest way of the room. The bearing timbers may be so arranged as to tie in the principal walls, and if the building forms a corner, having two or more external walls, they may be laid in opposite directions in the alternate stories. All parts of timber built into walls should have clear spaces round them for circulation of air. Timbers passing over several points of support, such as joists over binders, joists or binders over party walls, and similar cases, should be in as long lengths as possible, by which their strength is greatly increased as compared with what it would be if they were cut into short lengths, just sufficient to span the intervals between each pair of supports.

Fixing uniformly loaded timbers rigidly at the ends increases their strength by one-half, but this can seldom be done in practice. If the ends are built into the wall they have a tendency to strain and destroy the masonry. The want of a free circulation of air

causes the timber to decay, and in any case it soon shrinks and becomes loose.

All floors should be well ventilated, to secure a perfect circulation of air round all their parts. This is easily done by inserting air bricks in the walls. For the same purpose openings should be left in the sleeper walls carrying the intermediate wall plates of ground floors. The ground below the floor should be thoroughly drained, and covered with concrete to prevent damp from rising.

Ceiling Joists.—These are light beams to carry the laths for the plastering of the ceiling. They are fixed to the under side of the bearers of the floor, running at right angles to them; that is, in a Single Floor to the bridging joists, in a Double or Framed floor to the binding joists. They should be 14 in. from centre to centre where double laths are used; if more widely placed than this, the laths are likely to give with the weight of the plaster. With thinner laths the joists must be closer together. Two inches is the best width for ceiling joists. This is sufficient for nailing the laths. If wider, the under surface of the joist interrupts the key for the plaster.

Notching.—The mode of fixing ceiling joists is generally to notch them and nail them, as shown in Fig. 437.

Chase-mortising.—Sometimes, however, the depth from the ceiling to the surface of floor has to be kept as small as possible, in order to gain space. With this object the ceiling joists may be tenoned in between the bridging joists or binders with chase mortises, formed either as at *x* or as at *y*, Fig. 470. This should, however, be avoided as much as possible, for the mortises weaken the bearers.

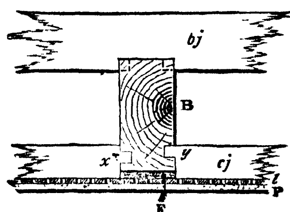


FIG. 470.—Ceiling Joists Chase-mortised into Binder.

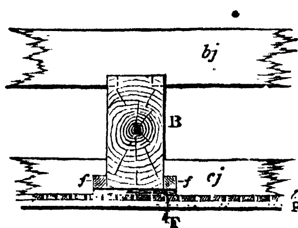


FIG. 471.—Ceiling Joists supported by Fillets fixed to Binder.

Filleting.—Another plan is to support the ends of the ceiling joists (*ff*) upon fillets nailed to the bridging joists, as shown in Fig. 471. Where ceiling joists are fixed in between bearers, their lower edges are allowed to come a little below the latter, a firring (F in Figs. 470 and 471) not wider than the ceiling joists being attached to the bearer below, so as to afford a key for the plaster.

Scantlings for Joists and Girders.—Three tables are appended giving the sizes of timbers recommended by Tredgold for single or bridging joists from 5 to 25 feet span, binding joists from 5 to 20 feet span, and girders from 10 to 36 feet span, between the bearings.

[TABLE

SIZES FOR FLOOR TIMBERS

TABLES OF SCANTLINGS

TABLE of the SCANTLINGS recommended by Tredgold for SINGLE or BRIDGING JOISTS of Baltic pine for different spans from 5 to 25 feet —the distance from centre to centre of the joists being 12 inches.

Length of Span in Feet.	Breadth 1½ in.	Breadth 2 in.	Breadth 2½ in.	Breadth 3 in.	Breadth 4 in.
	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.
5	5¾	5¼	4¾	4⅜	4
6	6¼	5¾	5⅜	5	4½
8	7¾	7	6½	6¼	5¾
10	9	8	7½	7	6½
12	10	9¼	8½	8	7¼
14	11	10	9½	9	8
16	12¼	11	10½	9¾	8⅞
18	13¼	12	11¼	10½	9½
20	14¼	13	12	11¼	10¼
22	15	13¾	12¾	12	11
24	16	14½	13½	12¾	11¾
25	16½	15	14	13	12

TABLE of SCANTLINGS recommended by Tredgold for BINDING JOISTS of Baltic pine for different spans from 5 to 20 feet when the distance from centre to centre is 6 feet.

Length of Span in Feet.	Depth, 6 in.	Depth, 7 in.	Depth, 8 in.	Depth, 9 in.	Depth, 10 in.	Depth, 11 in.	Depth, 12 in.
	Breadth, inches.	Breadth, inches.	Breadth, inches.	Breadth, inches.	Breadth, inches.	Breadth, inches.	Breadth, inches.
5	4¾	3	2				
6	6¾	4	3	2			
7		5½	4	2¾	2		
8	..	7	5	3¾	2¾	2	
10	..		8	5½	4	3	2½
12	..	..		8	6	4½	3½
	Depth, 13 in.	Depth, 14 in.	Depth, 15 in.				
	Breadth, inches.	Breadth, inches.	Breadth, inches.				
14	..	..	..		8	5¾	4½
16	4½	3¾	3¼	..	10¼	7¾	6
18	5¾	4¾	4	..		10	7½
20	7¼	6	4¾	..	..		9½

TABLE of the SCANTLINGS for GIRDERS of Baltic pine recommended by Tredgold for different span from 10 to 36 feet—girders 10 feet apart from middle to middle.

Length of Span in Feet.	Depth, 10 in.	Depth, 11 in.	Depth, 12 in.	Depth, 13 in.	Depth, 14 in.	Depth, 15 in.	Depth, 16 in.	Depth, 17 in.	Depth, 18 in.
	Breadth, inches.	Breadth, inches.	Breadth, inches.	Breadth, inches.	Breadth, inches.	Breadth, inches.	Breadth, inches.	Breadth, inches.	Breadth, inches.
10	7½	5½	4¼	3½	2¾				
12	10½	8	6	5	3¾	3¼			
14	14½	10¾	8½	6¾	5¼	4½	3½		
16	18¾	14	11	8¾	7	5¾	4¾	4	
18		17¾	14	11	8¾	7¼	6	5	4
20	..		17	13½	10¾	9	7¼	6	5¼
22	..	..		16½	13	10¾	8¾	7½	6¼
24	..	..		19½	15½	12¾	10½	8¾	7½
26	..	..	..		18¼	15	12¼	10¼	8½
28	..	..	..	..		17¼	14¼	11¾	10
	Depth, 19 in.	Depth, 20 in.	Depth, 21 in.						
	Breadth, inches.	Breadth, inches.	Breadth, inches.						
30	9¾	8½	7¼	..	..	19¾	16¼	13½	11½
32	11	9½	8¼	..	..		18½	15½	13
34	12½	10¾	9½	..	..	..		17½	14¾
36	14	12	10½	..	..	..	..	19½	16½

CHAPTER XVII

PARTITIONS

By Alan E. Munby, M.A., F.R.I.B.A.

Definition.—Partitions are internal divisions used in buildings in place of ordinary walls to economise space, weight, and expense. Until recent years, such divisions were made almost exclusively of timber

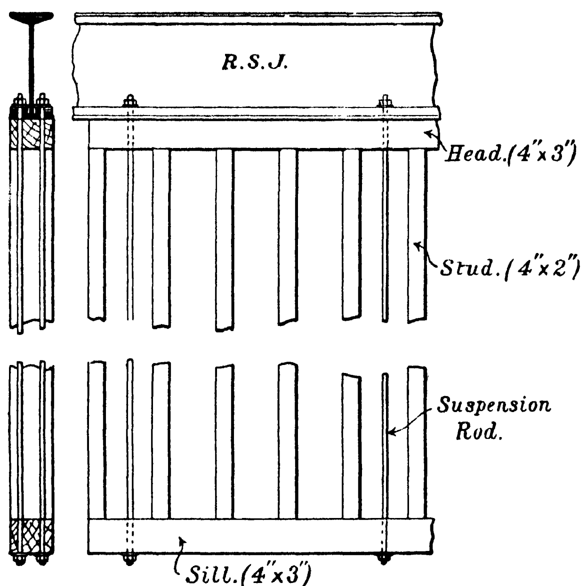


Fig. 472.

framing, covered by lath and plaster. In modern buildings it is becoming increasingly common to make the partitions of fire-resisting materials, and entirely independent of the main structure, thus permitting the subdivision of the different floors to be varied to suit the needs of tenants.

Partition Loads.—The ordinary wood partition can be trussed so that its weight is thrown upon the walls, but the modern partition usually gives a distributed load, and carries little or no weight from loads above it. With many fire-resisting floors the load due to a partition itself may be neglected, but if its weight is not within the loading figure of the

floor, special means must be provided for its support. Partitions have occasionally to be slung from some support above, as in an old building, where a wood partition is called upon to take further loads. This may be accomplished by steel suspension rods, with nuts and large washers below the partition sill, or, if the supporting beam is a steel joist, by rods placed alternately on either side of the web, piercing the lower flange and fixed with bolts and wedge-shaped washers, as shown in Fig. 472. The rods should be well distributed and calculated in total section for the load to be carried. Where partitions have to be erected on existing floor boards, a sill piece should be first fixed to the floor to help in the distribution of the load, and for fixing joinery dressings.

Wood Partitions.—Wooden or *stud* partitions are advantageous in that they are light, require no special material, offer a good fixing for dressings, and lend themselves well to irregular boundaries. They are disadvantageous in that they are inflammable, harbour vermin, transmit sound readily, are thicker than some other types, and are subject to the forms of decay common to timber.

Simple Wood Partitions.—These have a continuous bearing along their whole length on solid floors, walls, or other sufficient support, and consist of a sill, head, studs, and horizontal struts. Such a partition is shown in Fig. 473, where *ss* is the sill, usually 4 inches by 3 inches, H is the head of the same dimensions, *st* are the studs, also known as *quarterings*, usually 4 inches by 2 inches, presenting 2 inches on the face of the partition, and *n* are the horizontal struts, or *nogging pieces*, of the same section as the studs. The studs are generally placed 12 inches apart from centre to centre, and if laths are to be fixed thereto, the distance apart should be some submultiple of the lath length. The struts are placed in rows every 4 or 5 feet, and are fixed as shown to enable them to be conveniently nailed to the studs. They are often formed from waste cut from the studs on erection. If the partition is to be plastered, they should be kept back from the stud face to prevent interference with the plaster key, while if boarding is intended they may be flush to give additional fixing. The studs should be tenoned to the head and sill, which usually overrun the partition by some 4 or 5 inches, pockets being cut in the walls to receive these projections. In the case of a simple partition, however, this is merely to secure the structure against lateral pressure. Where openings

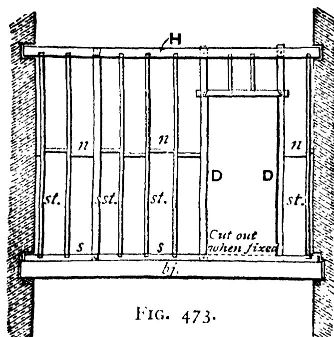


FIG. 473.

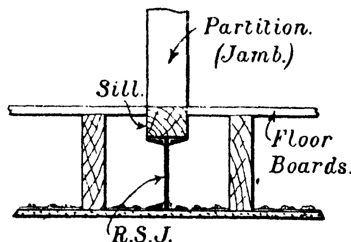


FIG. 474.

are required, wider studs, called *door studs* or *principal posts*, D D, are introduced, running the full height of the partition, with a head framed between them, as shown in Fig. 473. If the support is a joisted floor and the partition runs across the joists, the sill must be cut out in such opening, but if the joists run with the partition the sill may sometimes be kept below the floor by using a steel joist as in Fig. 474, the sill being kept flush with the floor boards if necessary.

Trussed Wood Partitions.—Where a wood partition has to be placed upon a floor unable to carry it, and a steel joist below the sill is impractic

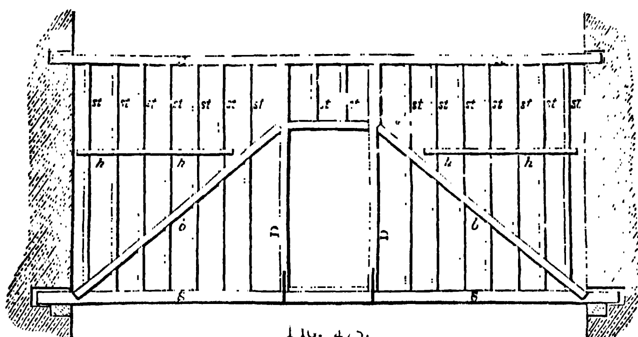


FIG. 475.

able, the partition may be trussed. The principles of king and queen post trusses are applicable to such cases. The sill must be regarded as a tie beam, and the studs must be cut on the splay to principal rafters framed to a king post, or if an opening is required, to queen posts, which form the jambs of such aperture. The studs above the principal rafters may then be regarded as mere filling, the load being usually borne entirely by the feet of the truss, which must have a sufficient bearing on templates built into pockets in the walls. Fig. 475 shows such a truss with a central doorway, the straining beam forming the head or lintel of the opening. If the opening is not near the centre, a complete

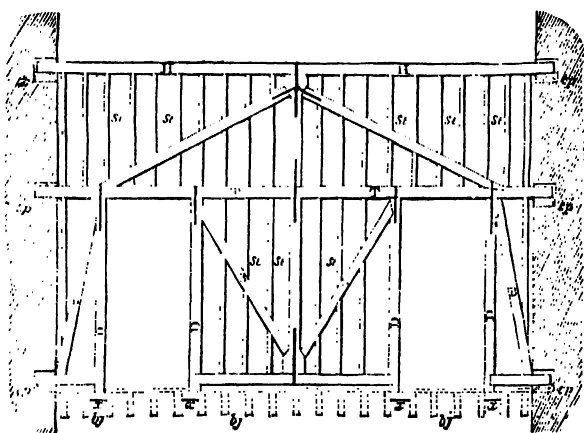


FIG. 476.

truss may be formed above and the framing below. The tie beam, which then forms the head of the opening, is suspended from this tie. Fig. 476 shows such a truss with two side openings, but since the introduction of steel such forms of trussing have become much less common in modern practice.

Filling-in to Wood Partitions.—Various materials have been employed for filling in the space between the studs of wooden partitions. A common practice, never now adopted, consisted in filling the spaces with ordinary bricks, which was known as *brick nogging*. Saw-dust has been used, but is affected by damp and decay, and is very inflammable. Cork waste is preferable and very light, but is more costly. Should filling be necessary, probably the best material is slag wool, which is light, incombustible, and sanitary.

Brick Partitions.—Under this heading, half-brick and brick on edge walls are considered. Such partitions have the advantage of being readily erected, and are incombustible. They are, however, heavy, possess restrictions as regards safe area without piers, and are less strong than some other types, especially where cut up by openings.

Simple Brick Partitions.—Simple half-brick walls require little comment. The bricks are necessarily all laid as *stretchers* and should be built in cement mortar. Where no covering is intended the difficulty of obtaining two fair faces may involve the necessity of selecting bricks, and where glazed dados or bands of different bricks are proposed the possibly varying width of such materials should be duly considered.

Reinforced Brick Partitions.—If the tensile stresses to which mortar joints are subjected under forces other than compression be taken up by metal reinforcement distributed in the bedding joints, great additional strength is given to thin brick walls. This addition may take the form of steel wire mesh, expanded metal, steel wire, or steel strip. Several forms of mesh for such use have been patented. These are made 2 and 2½ inches wide, and therefore are completely enclosed even in a brick on edge wall. An advantage sometimes valuable in construction is that reinforced brick partitions will carry themselves over moderate spaces without foundations, thus permitting concentration of the load on cross walls or piers.

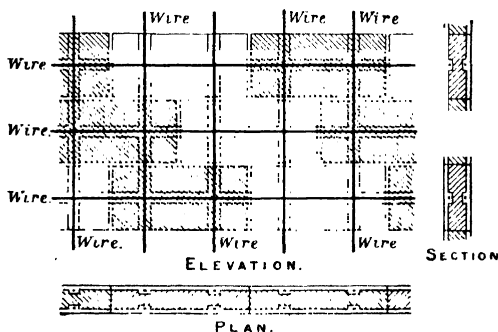


FIG. 477.

It is not generally necessary to reinforce more than every third or fourth course. A patent form of reinforcing surface wire used with special indented bricks and finally held in place by the plaster finish is shown in Fig. 477.

Terra-cotta Partitions.—Terra-cotta blocks, varying in face dimensions from about 18 inches by 9 inches to 12 inches by 6 inches, are very largely used for partitions. They are usually made rough for plaster, and should be laid in cement mortar. In thickness these blocks range from 1½ inches to 8 inches, those measuring 3 to 4½ inches having the widest use.

Terra-cotta Partitions for Plaster.—The blocks for these take many forms, some are keyed or grooved on the edges; usually they are scored for rendering, and are open at the ends as in Fig. 478. Some types are laid vertically, that is, with the open ends forming the bedding course, but if the interior spaces are large this is open to considerable objection, and the blocks should usually be placed horizontally, unless it is intended to fill the spaces in the blocks with mortar. If the blocks are not well wetted, both before laying and subsequently on rendering, water from the mortar may be absorbed before setting is complete, with great detriment to the strength of the work. Special provision must be made for fixing joinery dressings, and although ordinary terra-cotta will not take nails, blocks are made specially fired for this purpose, and are undoubtedly more desirable than breeze blocks. Fixing blocks should be marked in some distinctive manner, and built in courses to suit all dressings, which therefore should be decided upon at an early stage. Such blocks are rather heavier and more costly than ordinary blocks, their weight per square yard being about 140 lb. for blocks 3 inches thick and 170 lb. for blocks 4½ inches thick, exclusive of plaster covering, which weighs some 45 lb. per square yard for each side.

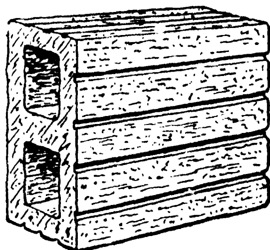


FIG. 478.

In American practice it is usual to wedge the top of terra-cotta partitions tightly against the ceiling bearing. This gives great additional strength, and is desirable when a rigid bearing is obtainable, both above and below. Usually, however, such partitions are merely steadied at the top by fillets between joists or behind cornices. Where fire-resisting ceilings occur a cement joint can be made.

Terra-cotta Finished Face.—Blocks which require no covering, although relatively costly, save space and total outlay, and are suitable for buildings where appearance is not important. They are simply flush pointed, and the surfaces of the partition are usually distempered. Blocks with glazed faces have a limited application for sanitary and similar works. They weigh more than ordinary blocks, and as a rule do not give so good a key for jointing.

Concrete Partitions.—These are made of concrete, applied either in the form of slabs previously moulded, or moulded *in situ*. In the latter case some reinforcement is usual. The merits of various aggregates employed for suspended concrete work are dealt with in Chapter XIV. Concrete partitions are now rarely made *in situ*, as the expense of moulds

and the tendency to inequality in the mixing and composition at different heights introduce undesirable factors where very thin walls are concerned.

Slab Concrete Partitions.—Slabs of pumice, breeze, or cinder concrete are largely used in second-class work, and are both cheap and light. Various forms of slab are available, often ingeniously keyed on the edges. They are usually from 12 inches to 18 inches wide, by 3 feet long by from 1½ to 4 inches thick, and consist of 1 part of cement, 1 part of sand, and 4 to 5 parts of aggregate. The actual composition should be ascertained in every case, and no such slabs should be used without a guarantee of at least three months' seasoning, since when *green*, the slabs are liable to change appreciably in dimensions, sometimes cracking as a result. Cement mortar should be used for setting partition slabs of this kind.

Reinforced Concrete Partitions.—Partitions in this material are not largely used apart from reinforced concrete buildings. Interlaced vertical and horizontal rods are most frequently employed as reinforcement, although expanded metal fixed to steel uprights is also used. This construction may be exemplified by the Roebling partition used in America, one form of which consists of 2 inches by ⅛ inch vertical steel flats at 18-inch centres turned up at each end and fixed to floor and ceiling, to which ¼-inch horizontal rods, 7½ inches apart, are wired, expanded metal being then laid upon each side, and the whole filled in with 1 to 8 cinder concrete, and finally plastered, producing a structure 4 inches thick and weighing about 32 lb. per square foot.

Plaster Partitions.—These are usually made of plaster of Paris sometimes hardened by the admixture of small quantities of borax, or other compounds employed in the manufacture of special plasters or so-called *cements.* Such plasters may be formed in slabs or applied to suitable skeleton framing.

Slab Plaster Partitions.—Plaster slabs are light, readily handled, can be cut or sawn, and are both cheap and rapidly erected. They are poor fire-resisters, as they become friable under heat. They are also very absorbent, moisture having a great tendency to work down to the floors on their erection. A mixture of plaster of Paris and sand is usually employed for jointing in as thin layers as is compatible with complete covering of the edges. In dimensions, plaster slabs resemble those made with Portland cement, but are often cast with cylindrical longitudinal cores to economise material. Partly for the above reason and also to give additional strength for transit and handling, wood-fibre, reeds, canvas, and like substances are generally added. Mineral asbestos is excellent for this purpose, but its cost is such that the proportion contained is often a great deal smaller than the designation of some slabs would suggest. When the slabs are not solid they are placed with the cores horizontally, unless cutting is required at the top of the partition. In such cases the cores should be vertical and filled in. Plaster partitions cannot be wedged, and must be merely steadied at the top by suitable side fixings in ceilings.

Reinforced Plaster Partitions.—Many types of metal skeleton frames upon which plaster may be directly laid are in common use, and although

plaster alone is applied in many cases, a rendering of cement mortar on the metal is desirable, both to avoid risk of corrosion and to give a good hold to the filling material. One form of partition consists of ⅞-inch steel channels, fixed vertically at 16-inch centres, with angle bars at floor and ceiling, and one side covered by expanded metal. Afterwards a rendering of cement mortar is applied to both sides, producing a solid structure 2 inches thick. Another variety, attempting to combine both the supports required for rigidity and the laying surface in one metal unit, is the "Hyrib" partition, which consists of sheets of expanded metal with stiffening ribs, as represented in Fig. 479. The sheets, 10½ inches wide and up to 12 feet long, which are used either vertically and horizontally, are lapped and wired to constructional steel or other supports, and with the aid of temporary strutting during erection, may be employed for spans up to 12 feet. Another type of reinforcement is represented by metal ladder tape. This is a steel band, so cut that when pulled out on use it assumes a ladder-like form, and is strained between supports vertically and horizontally, forming a series of 12-inch squares. Centring is then erected on one side, and filling applied to enclose the metal work completely.

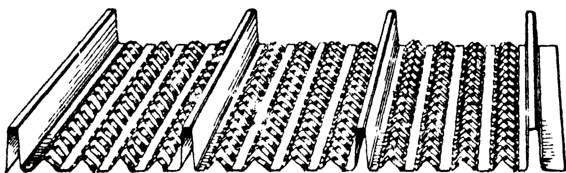


FIG. 479.

Openings in Modern Partitions.—In stud partitions necessary openings can be made part of the structural framing, but in the new types, unless vertical steel members are present which can be suitably spaced, special consideration of the effect of openings is often necessary. By destroying continuity all openings tend to weaken thin walls; consequently solid frames in place of linings are required for such openings. Unless a partition is very ample in strength for its situation and area, it is desirable to carry the jambs of framed openings to the ceiling to obtain rigidity, which is naturally more necessary where doors are to be hung to such frames. Frames should be at least of the full finished thickness of the partition; hence if the frame is carried up difficulties arise, unless the architraves can be similarly continued and a panel formed above the door, which is usually undesirable. If the partition is 5 inches or more thick, the jambs above the door-head may be reduced sufficiently to enable expanded metal to be placed slightly in front of them, on which the final plaster coat may be laid. Fig. 480 shows such an arrangement. For thinner partitions iron or steel rods, flattened at the ends and screwed to the sides of the jambs, may generally be employed, as in Fig. 481. Wood frames, which ought to be from 2½ inches to 3 inches thick, should be rebated in the solid for doors, and architraves (unless of great width) may be fixed to the frames without grounds (see Fig. 482). A better plan, however, is to rebate the back of the frame, and work one architrave on the solid,

which gives additional strength. Fig. 483 shows a plan of this type through a door jamb, usually adopted in hospital practice. Suitable terra-cotta,

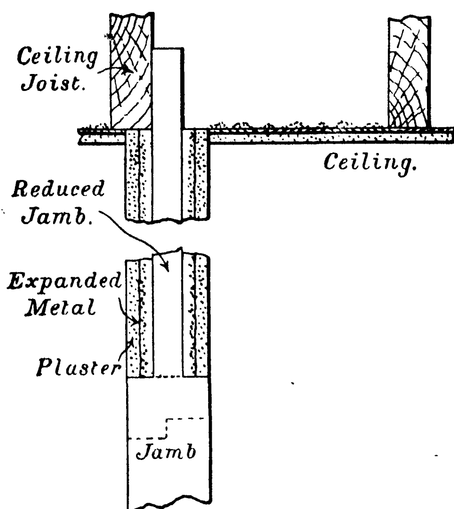


FIG. 480.

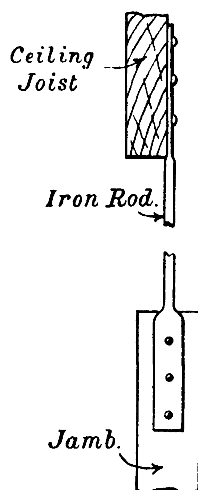


FIG. 481.

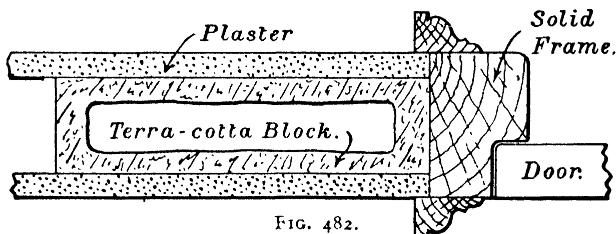


FIG. 482.

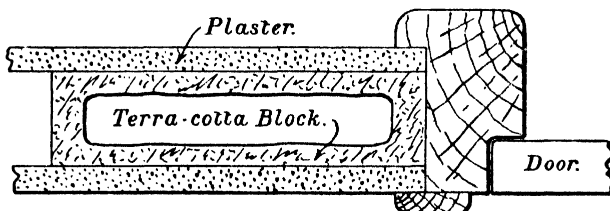


FIG. 483.

breeze, or steel strip fixings must of course be provided in openings for such frames. Where it is necessary, on account of fire risks, for instance, to reduce woodwork to a minimum, joinery dressings may be replaced very largely by finished face terra-cotta blocks, reinforced concrete, or even

cast-iron dressings. Door frames, skirtings, dado, and frieze rails may all be thus dealt with. Fig. 484 shows a plan through a terra-cotta jamb, in the *ploughed* face of which a rebated lining of wood is fixed by small bolts, having sunk nuts, which are stopped before painting. The jamb blocks are laid with the cores placed vertically, and these should be filled in with concrete as they are erected. In the case of cast-iron frames, the frame, door stop, and architraves are cast in one piece, an opening being left at the back for insertion of the partition, built subsequently to their erection. The doors can in this case be hung direct to the iron frames, which are tapped for hinges.

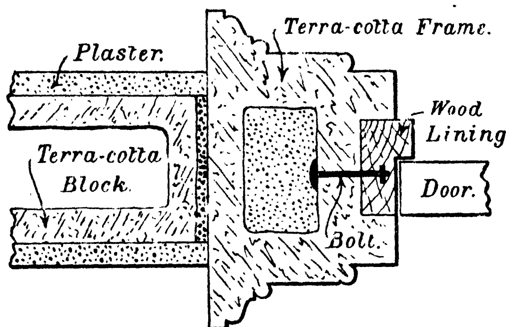


FIG. 484.

Lintels to Openings.—Where openings are small and frames of liberal dimensions, the head of the frame is often sufficient to carry the superincumbent load without sagging. In other cases provision must be made to relieve the frame of load. For openings of moderate size some horizontal reinforcement in the form of wire-mesh or steel strip for three or four courses in the case of brick or terra-cotta, or steel rods in the case of concrete formed *in situ*, carried 2 or 3 feet beyond the opening on either side, will be found simple and efficient. For large openings a steel joist covered with expanded metal for plaster may be requisite, although hardly practicable in the case of very thin partitions, where reinforcement of the courses over the opening, coupled with an increased depth of frame head, will generally meet requirements.

Partition Coverings.—The finishing of partitions admits of so much variation that information should be sought in Part III. under the headings of the material proposed. For "Plastering" see Chapter IX. Part II.

Plaster of Paris, either alone or upon laths or expanded metal, is suitable in any situation which is dry and where a suitable key is obtainable. Many special plasters may be used for exterior as well as for interior work. Where timber is in contact with plaster, care must be taken that the width of face exposed does not too greatly break the key. If the timber exceeds 2 inches on the face it should be rebated in order to reduce it to this width, or *counter lathing* must be adopted.

Where a boarded surface is required, fillets must first be fixed to breeze or terra-cotta fixing blocks in solid partitions. In the case of stud partitions, if the boarding is to be fixed vertically, additional horizontal strutting pieces will be required. To counterbalance the cost of these, the studs may be placed rather farther apart. Horizontal struts, however, are not necessary where composition boards, which are obtainable in large

widths, are used. It is desirable to paint the tongues of boards before erection if the surface of the work is to be thus finished to prevent an unsightly appearance should shrinkage occur.

Various forms of incombustible sheets, composed of cement or plaster, with wood, asbestos, or similar binder, are now available as coverings.

APPENDIX

SELECTED EXAMINATION QUESTIONS

In previous editions of *Rivington's Notes*, an Appendix to Parts I and II contained complete Examination Papers set by the Board of Education, the questions relating to subjects treated in all four Parts of the work. Having regard to the fact that this collection of Notes is used by a far wider class of students and readers than that originally in view, it is appropriate that the Appendix should include Examination Questions set not only by the Board of Education but also by other bodies by whom examinations are held in Building Construction and allied subjects. Moreover, a departure has been made from the practice, hitherto followed, of including in Parts I and II questions which could not be answered without reference to Parts III and IV. The arrangement now adopted is to give in each Part a selection of questions bearing upon the subject-matter in the body of the volume, and it is hoped that this new feature may be found helpful to students of all classes.

The examination questions printed on the following pages have been selected from those set by the Royal Institute of British Architects, the Board of Education, the City and Guilds of London Institute, the Surveyors' Institution, the Royal Sanitary Institute, the Municipal School of Technology, Manchester, and the Royal Technical College, Glasgow.

Full particulars relative to the examinations of the Royal Institute of British Architects are given in the *R.I.B.A. Kalendar*; the syllabus of the Board of Education will be found in *Regulations and Syllabuses for Examinations in Science and Technology*, and complete series of papers in *Examinations in Science and Technology*; information as to the examinations of the Department of Technology of the City and Guilds of London Institute may be obtained from the *Report on the Work of the Department*; the Syllabus of subjects and examples of papers set by the Surveyors' Institution are published in a pamphlet entitled *Examinations*; particulars of examinations held by the Royal Sanitary Institute are given, together with selected questions, in a pamphlet issued by the Institute. The calendars of the Municipal School of Technology, Manchester, and of the Royal Technical College, Glasgow, should be consulted by students requiring details of the work conducted by these institutions. All the publications mentioned are issued annually, those of the Board of Education and the City and Guilds Institute being obtainable through any bookseller, and the remainder on application to the respective institutes or colleges.

SELECTED EXAMINATION QUESTIONS

ROYAL INSTITUTE OF BRITISH ARCHITECTS.

Intermediate Examination.

Give a sketch showing the centring necessary for the construction of a concrete and steel floor, and explain what are the principal points to be considered in fixing such centring. How would you conduct the test of a concrete floor of this description?

How would you fix an iron railing on a stone coping? What method would you adopt if the railing were of wood? Give sections to a scale of 3 in. to 1 ft.

The facing bricks for a house are to be 2 in. thick. The internal bricks are 3 in. thick. Describe and illustrate the various ways of building the external walls.

Show by section and plan to 1-in. scale the proper construction and finish for a hearth: (*a*) on the ground floor; (*b*) on an upper floor. In both cases the floors consist of wooden joists and boarding.

How would you lay and fix on a concrete floor: (*a*) 1-in. flooring boards; (*b*) wood blocks? Give sections to a scale of 3 in. to 1 ft.

Draw to a scale of 1½ in. to 1 ft. a section through a chimney opening in a party wall, showing an ordinary register stove fixed in position and the construction of the hearth. A plan showing the trimming of the floor timbers is also to be given.

Give a sketch showing the foundations you would adopt for a three-story warehouse building 60 ft. by 40 ft. on soft clay soil.

State briefly the materials you consider best for the following purposes: (*a*) waterproofing a basement; (*b*) constructing a fire-resisting floor; (*c*) walls of a strong room; (*d*) foundation under a small cast-iron column; (*e*) fire-resisting door.

State three different forms of horizontal and vertical damp-courses, and give your views as to their relative merits.

What is the cause of dry-rot in timber? How would you detect it and what would you do to stop its development?

State very briefly the principle upon which the relative positions of the concrete and of the principal steel members in ferro-concrete beams are determined. Also say what is the purpose of "stirrups" in such beams.

Final Examination.

Give a list of the bearing capacity of the soils you are acquainted with, and the methods of forming the foundations on each, and the materials you would use, and the tests you would apply to ascertain the quality of each material.

Draw a section from front to back to scale of 2 ft. to 1 in., through the basement and lower ground-floor stories only, of a town building comprising sets of offices. The building to have a frontage to a public street and to be seven stories in height, including a well-lighted dry basement, with vaults 10 ft. wide constructed under the public footway. The floors to be fire-resisting. The basement to be 9 ft. high in the clear and its floor line to be 13 ft. below the street level. The lower ground-floor to be 10 ft. high. The site measures 48 ft. from front to back; a space 3 ft. wide along the front may receive pavement lights, and an open space 10 ft. wide to be provided at the rear, with the basement story extending under it. Adjoining the rear of the site is a double line of railway, the rail level of which is 6 ft. lower than the basement floor line, and a retaining wall is required there. Below the floor line of the basement the site consists of sand for a depth of 3 ft., then there is running sand 3 ft. in thickness, and below that good stony gravel. The walls throughout are to be built of brickwork, except the front above the street level, where stonework is intended.

It is proposed to form a basement to a building, the particulars of which are as follows: (*a*) it consists of a shop on the ground floor with three stories over; (*b*) it stands at the corner of a narrow street—say only 20 ft. wide—and is one of a terrace of houses in the main road; (*c*) the width of the shop window in front is 15 ft., and the

width of the shop window abutting on the side street is 20 ft., and the two bressummers meet at the corner where they are carried by one column. There are two windows in each front on each story above the ground floor. Make drawings to a scale of 4 ft. to 1 in., showing how you would needle and shore up the building. It is to be assumed that, in consequence of the age and condition of the building, flying shores are required across the side street and raking shores are required to the front. The plan should show all the shores and their position, but the other drawings of the building need only be sufficient to show one set of raking shores and one set of flying shores across the side street, and the needling up; but the shoring of the party and rear walls need not be shown. The scantlings of the shores are to be figured throughout.

You are called in to advise upon a damp basement in a suburban house. You find the conditions are: (a) the floor is 4 ft. below the ground level; (b) the walls on three sides of the building are against the earth, which is gravelly clay; (c) there is no horizontal damp course. Describe and illustrate the methods you would adopt to carry out the necessary work in the most economical manner.

Specify the materials for and the method of setting an ordinary wash-house copper. Illustrate your answer by sketches.

Give a list of four kinds of fire-resisting floors and the materials used in their construction and the merits or demerits of each.

What materials would you use to protect the structural steelwork in a building from fire, and what are the minimum thicknesses that you would give to protect the various members?

Sketch some sections of "built-up" stanchions, and indicate those you consider the most economical for the sectional area of metal used. Give reasons for your answer.

Draw a plan and section of a reinforced concrete pillar.

There is a large rectangular corner building with streets on two sides and buildings on the other two sides. The ground-floor elevations consist of large shop windows with intermediate brick piers and steel girders supporting the superstructure. The interior of the building on each floor is used as a large open showroom. The floors consist of wood joists carried on steel joists in both directions, which latter rest on the brick piers and walls and on intermediate cast-iron columns. The ceilings and walls are matchlined. A bad fire takes place on the premises, the interior being completely gutted. Describe what will be the probable effect, after extinction, on the steel girders and joists, the cast-iron columns, and the brick piers and walls.

In erecting a steel-frame building how would you protect the stanchions and girders from fire?

BOARD OF EDUCATION.

BUILDING CONSTRUCTION.

Lower Examination.

A two-story house is to be built with hollow brick walls, consisting of a 9-in. and a 4½-in. wall, with a 2-in. cavity. State whether you would put the 4½-in. wall on the outside or the inside, and give your reasons fully. Draw to a scale of 1 in. to 1 ft. a vertical section through a window opening 4 ft. high in such a wall, showing the cavity above the head and below the sill.

Describe and illustrate by sketches any two systems of fire-resisting floor construction with which you are acquainted.

Draw to a scale of 4 ft. to 1 in. a vertical cross-section through a pier hole 10 ft. square and 12 ft. deep in loose soil, and describe in their proper order the operations of the excavator in digging the hole.

Draw to a scale of 2 ft. to 1 in. plans of two consecutive courses of bricks laid English bond at the external angle of a building where a 2-brick wall meets a 1½-brick wall, showing the bond clearly.

Explain, with sketches, the meaning of the following: Fox-wedged tenon; Tusk tenon; Dovetail joint; Bird's mouth; Rule joint; and state in what circumstances you would use them.

Draw to a scale of 2 ft. to 1 in. two consecutive courses of bricks laid English bond in a square brick pier 3½ bricks thick each way.

Describe clearly the objects of a damp-course, and name three kinds of materials that are used for this purpose. In what positions in a building, other than near the ground level, are damp-courses desirable?

Explain clearly, with sketches, the meaning of the following terms: quoin; perpend; spandrel; dragon-piece; throat.

Draw to a scale of 2 in. to 1 ft. a section through a stone cornice crowning an 18-in. wall, the cornice to be 14 in. deep, with 18-in. projection from face of wall, and to have a blocking course on top. Describe fully how you would joint the cornice stones.

Higher Examination.

Explain, and illustrate by sketches, any two systems of ferro-concrete construction with which you are familiar, (*a*) as to floor beams, and (*b*) as to piers. In supervising such construction, what are the principal points to which you would direct your attention in order to guard against failure?

Draw to a scale of 4 ft. to 1 in. the elevation of the timber centring that would be required for a semicircular stone arch of 25 ft. span, the width of the soffit being 2 ft. Figure the scantlings of the timbers, and show clearly how the centring would be supported. Also draw a cross-section through the centring to a scale of 2 ft. to 1 in.

An upper floor of a warehouse is to be constructed of 12-in. × 6-in. rolled steel joists 10 ft. apart centre to centre, and 6-in. × 3-in. steel lacing joists; the whole of the steelwork is to be encased in fire-resisting materials, and the floor is to be wood block. Draw, one quarter full size, a cross-section of the large steel joist, showing clearly (*a*) the connexion of the small joists to it; (*b*) the fire-resisting casing; and (*c*) the wood block floor: also describe fully the fire-resisting casing.

Explain, with sketches, the essential difference between ferro-concrete construction and ordinary steel and concrete; and the advantages and disadvantages of each. Give three specific instances where you would prefer to use ferro-concrete rather than any other material, stating your reasons fully.

A narrow city street, 20 ft. wide between the house-fronts, has a roadway for traffic 12 ft. wide, and foot pavements 4 ft. wide. On one side of the street are modern, well-built warehouses, and on the other side a row of old shops with two floors over. The heights above pavement level are, respectively, 13 ft. to first-floor level, 23 ft. to second-floor level, and 33 ft. to the coping. One of these old buildings has bulged considerably, and has to be shored up. Draw to a scale of 4 ft. to 1 in. the system of shoring which you would adopt. The traffic in the roadway must not be interrupted.

Competitive Examination for Scholarships, etc.

Draw to a scale of 1 in. to 1 ft. a section through the footings of a wall 2½ bricks thick with the concrete foundations. If the outside dimensions of the building are 45 ft. by 25 ft., calculate the number of bricks that would be required for the whole of the footings of the four walls and the amount of the concrete.

If a brick wall is to be faced with thin bricks rising six courses to the foot, including mortar joints, with a backing of ordinary bricks rising four courses to the foot, explain clearly, and illustrate by sketches, how you would arrange for satisfactory bonding.

The brick wall of a three-story warehouse 40 ft. high from ground level to top of parapet shows signs of bulging; the first and second floor levels are respectively 14 ft. and 26 ft. above the ground, and the height of the top floor is 10 ft. clear, the roof being flat. Draw to a scale of ½ in. to 1 ft. a side elevation of the raking shore which you would put up, and the connexion of the top of highest raker with the wall to a scale of ⅛th full size.

A 12-in. by 6-in. rolled steel joist, acting as a stanchion, has to carry a load of 36 tons: draw a plan of its base plate and two elevations showing clearly the connexion of the stanchion to the base plate: scale of 1½ in. to 1 ft. On ordinary ground, what should be the area of the concrete block on which such a stanchion would stand?

State three of the principal causes of smoky chimneys, and describe the measures which you would adopt to cure the evil in each case.

CITY AND GUILDS OF LONDON INSTITUTE.

DEPARTMENT OF TECHNOLOGY.

BRICKWORK.

Grade 1.

Which is the stronger bond, English or Flemish? Prove your answer by drawing to 1-in. scale alternate courses of a 14-in. wall 5 ft. long in each bond, indicating points of weakness.

(*a*) Under what conditions would you consider it desirable to construct a hollow in preference to a solid external wall? (*b*) Show by sketch sections how you would arrange 11-in., 16-in., and 20-in. hollow walls, showing the wall at its base with footings. (*c*) What precautions would you take in building to prevent moisture finding its way through the wall thus constructed? (*d*) What arrangement would you provide to get rid of water accumulating at the foot of such a wall and over lintels of openings therein? (*e*) Give detail sketches of the various wall ties with which you are familiar.

Describe what is meant by the following terms: (*a*) axed arches; (*b*) gauged arches; (*c*) camber arches; (*d*) relieving arches; (*e*) skewback; (*f*) extrados; (*g*) intrados.

Show sections, full size, of the different kinds of pointing you know, and state for what purpose you consider each best suited. What type of damp-course would you adopt both for horizontal and vertical?

(*a*) Give a list of the different bonds you are acquainted with. (*b*) Set out to 1-in. scale separate plans of alternate courses of English and Flemish bonds to a wall as shown in the sketch. (*c*) Which is the stronger bond, English or Flemish? Mark on your drawing where you consider the points of weakness are.

What are meant by the following terms: (*a*) quoin; (*b*) reveal; (*c*) skewback; (*d*) gauged work; (*e*) intrados; (*f*) extrados; (*g*) soffit; (*h*) closer; (*i*) header; (*j*) stretcher.

What is the object and purpose of a damp-course? Where would you place it? What materials would you use for both horizontal and vertical damp-courses? What is meant by an "air brick"? State where and for what purpose you would introduce it into a building.

(*a*) Describe what is meant by the term "footings," and what principle governs the bonding of the bricks and the extent of the footings. (*b*) Draw to ½-in. scale sections of the footings and concrete, 12 in. thick, to a 1-brick, 1½-brick, 2-brick, and 2½-brick wall. (*c*) State the different kinds of damp-course known to you. (*d*) Show on each of the above sections where you would put the damp-course, indicating floor and ground lines.

Final Examination.

You have to sink an excavation 12 ft. deep, the last 8 ft. in running sand. Show by ¼-in. scale drawings how you would support the earth, marking the size of timbers, etc., required. Describe how you would keep the excavation clear of water. The above excavation is required for a watertight tank, 15 ft. by 20 ft. in clear. Show by sections how you would obtain this result.

Set out to 1-in. scale the following gauged arches: (*a*) Gothic arch, 3 ft. opening, 3 ft. radius, 14 in. on face, 9 in. on soffit; (*b*) elliptical arch, 4 ft. opening, 21 in. rise, 14 in. on face, 4½ in. on soffit; (*c*) camber arch, 3 ft. opening, 9 in. on face, 9 in. on soffit. State how many bricks would be required for each arch.

(*a*) Why are footings put to a brick wall? (*b*) What principle governs the bonding of the bricks in their construction? (*c*) Show by sections what footings you would put and how you would arrange the bricks to a 1-brick, 1½-brick, and 2½-brick wall. (*d*) Indicate on the latter section where you would put the damp-course and air brick, and also indicate the floor and ground level.

You have to excavate a building site, 175 ft. long by 50 ft. wide, to a depth of

18 ft. On one 175-ft. side there is an existing building whose footings are below the excavated level, the other three frontages are excavated up to the road, on which there is considerable heavy traffic. Show by plan and sections how you would proceed to timber, marking the size of timber you would propose to use. The nature of the soil is clay.

MASONRY.

Grade 1.

What is the "natural" bed of a stone? Why should stones be set in a building upon this bed? Would you make any exceptions, and, if so, why? Would it make any difference if the stone were set horizontal on the bed, but upside down?

State the principal agents of destruction to external stonework. Name any precautions which you would consider it desirable to apply to a new structure to prevent disintegration. Name four stones which on this account you would decline to use in an external situation in a city (London, for example), and state four others you would prefer in place of them.

Sketch sections of the following types of mouldings: Bird's-beak, Double Ogee, Scroll, Pointed Bowtell, Listel, Cavetto, Wave.

Set out to ¼-in. scale on your paper an ashlar stone facing, 8 ft. 6 in. high, in six courses, with fair quoins each end, the wall being 15 ft. long. Show the jointing and mark the depths of the beds thereon so as to produce an average of 6¾ in. depth. Number the stones so that the fixer may make no mistake in placing them.

Draw to ½-in. scale sections of the foundations of two stone-faced walls, one 1 ft. 4 in. thick, and the other 1 ft. 9 in. thick at base. State what purpose spreading footings serve, and if you consider that they are always necessary. Why is a damp-course put in? What materials do you consider best for its composition?

Show by sketches the following joints, and in what positions they would be properly introduced: Joggle, bed joggle, bed dowel, saddle joint, table joint, keyed joint.

State the functions fulfilled by mortar in a stone wall. Of what materials would you make it, and what qualities would you look for therein? State the chemical changes that occur in the mixing of the ingredients and in the maturing of the mixture. State also whether in your opinion lime or cement makes the better mortar for masonry, and why you think so.

For what reason is it necessary to carry foundations of buildings below the surface of the ground? How deep do you consider it necessary to go in order to secure safety in (*a*) clay soil, (*b*) gravelly soil? What weight per foot superficial would you consider it safe to place upon each of these soils? Show by a sketch how you would arrange to distribute the weight of the wall so as to get a larger bearing surface upon the soil and secure a uniform pressure upon the same.

Give definitions, as concisely as possible, of the following technical terms: (1) bed, (2) joint, (3) quoin, (4) drafted edge, (5) cramp, (6) dowel, (7) joggle, (8) throat, (9) voussoir, (10) Lewis.

What precaution would you take, in bedding the stones of a weight-carrying pier or column, to prevent fracture, or flushing of the arrises? How would you set thresholds and window sills so as to avoid subsequent fracture by settlement?

Give sketches of the following kinds of masonry: uncoursed rubble, coursed rubble, random rubble coursed, ashlar facing. Show how you would construct the angles of a building whose external walls were built of coursed rubble.

STRUCTURAL ENGINEERING.

Final Examination.

Sketch and describe a grillage foundation suitable for supporting a heavily loaded column in poor bearing soil. Briefly describe how you would determine the dimensions of the grillage, assuming that the load on the column and the base area of the column are known, and also the safe bearing pressure on the soil.

Describe fully, with sketches, two methods of reinforcing concrete piles. How are the heads of the piles protected from injury? Why is it necessary to consider whether this reinforcement is strong enough to resist a bending moment?

The main cross girders of a building are of reinforced concrete. They are built into the wall at each end, and are supported in the middle by a reinforced concrete pillar. Draw a sketch of a girder and pillar, showing clearly the disposition of the steel reinforcement, and say for what purpose each steel bar is introduced.

Design a grillage foundation for a column mounted on a 4 ft. square base and carrying a load of 200 tons. The pressure on the earth must not exceed 1½ tons per square foot.

Describe and illustrate by sketches the chief differences between the Hennebique, Considère, and Kahn systems of reinforcing concrete piles, columns, and beams. What are the special advantages claimed for each system?

CARPENTRY AND JOINERY.

Draw the elevation of a centre for a semi-circular brick arch of 10 ft. span, 3 ft. thick, and figure in the sizes of the materials used. Scale, ½ in. to 1 ft.

Show by sketches the following timbers to be used in a trench 3 ft. wide, 7 ft. deep, viz.: walings, poling boards, struts. Figure in the sizes that you would use.

It is found that the foot of a large system of raking shores shows signs of decay. Give clear directions for repairing or replacing the decayed parts without incurring any risk and with the object of avoiding a recurrence of the defects.

Draw part elevation and section (scale ½ in. to 1 ft.) of a gantry 15 ft. high, to be used to store stonework during the erection of an important building. Make sketches, half full-size, of the ironwork used, and name the various members of the structure.

An existing room, 11 ft. high, 14 ft. wide, has to be divided into two portions by a partition, with communicating door in centre. Give elevation, ½ in. to 1 ft., of the stud partition you would adopt, figuring in all sizes.

SURVEYORS' INSTITUTION.

Intermediate Examination.

Make a sketch showing how the basement of a house should be constructed, the floor of which is, say, 6 ft. below the ground level, in damp clay soil.

What means are available for preserving building stones from decay?

Explain by sketches (*a*) English bond, and (*b*) Flemish bond in brickwork, and (*c*) random rubble, and (*d*) squared rubble built in courses in masonry.

Sketch the shoring necessary to secure the street front of a dangerous building, 50 ft. high and 24 ft. wide; name and figure scantlings of the timbers.

Draw examples in carpentry of (*a*) fox wedging, (*b*) tusk tenon, and (*c*) dovetail notch.

Final and Direct Fellowship Examinations.

Give dimensioned sketches showing how to construct (*a*) hollow walls; (*b*) damp-proof courses; (*c*) connexions between roof, gutters, etc.

What causes dry rot in the timber of a house, and how can it be prevented or remedied?

ROYAL SANITARY INSTITUTE.

Describe the preparation of a water-logged site on which a healthy dwelling may be built.

In what manner would you examine and test a building site, the soil of which was suspected to contain some organic pollution, in a state of decomposition? How would you deal with this site in order to make it healthy? How would you construct the foundations of a large house on wet clay or sand?

What conditions give rise to dampness in the ground-floor walls of a dwelling? and what would be the practical remedy to apply in each case?

Describe the methods of construction that might be adopted with a view to obtaining a dry floor for a living room on the ground floor in the case of a house erected on a clay soil. How would you ensure that the floors of the upper rooms were reasonably sound-proof? Illustrate your answer by sketches.

Show by sketches sections through the basement walls and floor of a house constructed on a wet site; the basement is 9 ft. high, the floor level is 6 ft. below the surface of the surrounding ground. What material would you use for the damp-proofing, and how would you construct the basement floor?

By means of a section (drawn to a scale 1 in. to 1 ft.) through a 14-in. brick wall built in English bond, show the following: "footings," "ground level," "wall plate," "damp-course," and "air brick."

Give a description of the construction of a fireproof furniture store three stories in height, stating the materials which should be used for the walls, roof, floors, doors, windows, and staircase.

MUNICIPAL SCHOOL OF TECHNOLOGY: MANCHESTER.

BUILDING CONSTRUCTION.

First Year.

A wall is 9 in. thick, 12 ft. high, and 24 ft. long; 3 ft. of the wall is below ground level. Sketch a section of the wall to a scale of ½ in. = 1 ft., and calculate: (*a*) the number of cubic feet of excavation in the wall trench; (*b*) the number of bricks 9 in. × 4½ in. × 3 in. necessary to build the part of the wall which is above ground level.

A window opening 4 ft. wide between the reveals is finished on the outside with a straight-gauged arch 12 in. deep. Draw to a scale of 1 in. to 1 ft. the back elevation of the arch, showing a 4-in. lintel and a 9-in. relieving arch in two half-brick rings.

Draw the elevation of the upper part of a doorway 3 ft. 6 in. wide, showing a segmental arch in stone with a 9-in. rise. Show voussoirs 9 in. deep, with a keystone 15 in. deep. The sides of the opening are in plain ashlar, and the remainder of the wall in rubble. Scale, 1 in. to 1 ft.

State fully what you understand by the following terms: (*a*) lime mortar, (*b*) cement mortar, (*c*) concrete, (*d*) damp-course.

Illustrate by sketches the meaning of the following terms: (*a*) rivet, (*b*) rivet pitch, (*c*) flitch girder, (*d*) rolled steel joist, (*e*) cast-iron girder. The difference in section of (*c*), (*d*), and (*e*) must be clearly shown.

A room on the ground floor of a building is 12 ft. square, and has a fireplace in the centre of one of the walls. The walls are 14 in. thick. Draw a section through the centre of the floor and fireplace, showing 6-in. × 3-in. joists resting on wall plate, sleeper wall, and fender wall. Scale, ½ in. to 1 ft.

Second Year.

A house standing on a damp, clay soil has 16-in. cavity walls resting on brick footings and a concrete foundation. The ground floor is constructed of 5-in. × 3-in. wood joists

and floor-boards, and is about 1 ft. 6 in. above the level of the ground. Draw to a scale of 1 in. to 1 ft. a section through the wall, floor, and foundation, showing particularly what measures you would adopt to keep the damp from rising into the wall and rooms, and to prevent dry rot in the floor.

A brick chimney stack contains 4 flues. Give a plan of two alternate courses showing the bonding of the brickwork, and an elevation showing a treatment of the chimney cap, without the use of stonework, suitable for domestic work. Scale, ½ in. to 1 ft.

What is the safe load in tons per square foot you would place on gravel-ground? Describe a method of distributing the load on the foundations of (*a*) a four-story warehouse, (*b*) a heavy column.

Third Year.

The party wall between two warehouses is 18 in. thick. It is required to connect the two by an opening 20 ft. long by 14 ft. high. Assume that the floor beams do not rest upon the wall, that it is four stories high, that the brickwork weighs 112 lb. per cubic foot. Design a system of needle shoring to support the wall during the process of cutting away and building in the girder over the opening. Show clearly your calculations for the needles and dead shores.

ROYAL TECHNICAL COLLEGE: GLASGOW.

BUILDING CONSTRUCTION.

Preliminary Course.

Explain by sketches how you would prevent a stone mullion splitting where it stands over the vertical joint between two sills.

Sketch the plan of the joisting in the upper floor of a bay window, showing clearly how the joists are supported.

Course 1.

Draw to scale of 1 in. = 1 ft. plan and transverse and longitudinal sections to show the method generally adopted in Glasgow for the centring of a concrete floor. Show 5-in. by 4-in. steel joists.

Explain fully the steps you would take to preserve the white sandstone façade of a Glasgow building from decay if the building were (1) newly erected, (2) erected for, say, 10 years.

Draw to scale of 8 ft. to 1 in. the lower part of an 18-in. brick wall, 35 ft. long, forming the side of a house built upon the slope of a hill; the difference in level in the ground being 10 ft. Indicate the footings and concrete (in clay soil), the wall being 50 ft. high. Show also the damp-course, the floor being 5 ft. below the highest ground.

CARPENTRY AND JOINERY.

Course 1.

Draw to 1-in. scale the plan and elevation of a centre for a circle-on-circle stone arch semi-circular in elevation. Width of opening, 4 ft. Plan radius to concave side, 3 ft. Width of centre at crown of soffit, 1 ft. 6 in. From your drawing produce the shape of all the ribs, and make a development of part of the cleading.

Draw to 1-in. scale half plan, half elevation, and half section of a small hemispherical dome, 5 ft. in diameter. Show a few of the ribs and dwangs in plan, and develop part of the cleading. What is the most economical method of cleading the surface of a large dome?

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